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Full-Scale Machinery Space Water Mist Tests: Final Design Validation

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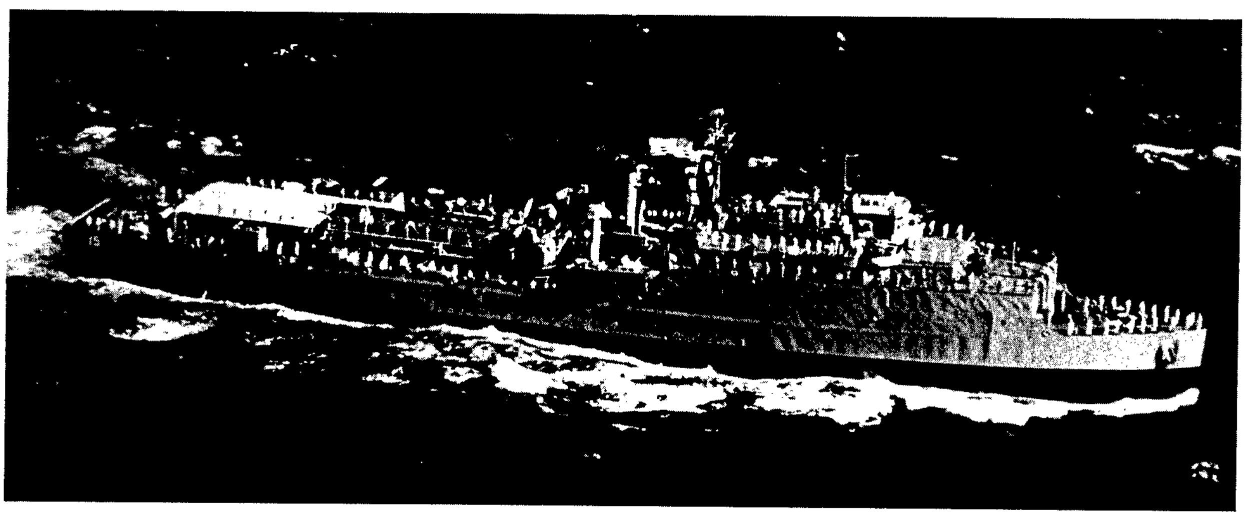

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13. ABSTRACT *(Maximum 200 words)*

The water mist nozzle developed in the early stages of the Navy's investigation into the use of water mist in machinery space applications was redesigned and revaluated during this test program. The nozzle was evaluated in a system design consisting of two levels of nozzles installed with a nominal 3.0 m (10 ft) nozzle spacing.

With the space secured (doors closed and the ventilation system secured), the water mist system was capable of extinguishing all the unobstructed fires in less than one minute, and all of the obstructed fires 1.0 MW or larger in less than three minutes and thirty seconds. The results of these tests were then scaled to the larger machinery spaces on the LPD-17. The scaling analysis suggests that the unobstructed fires would still be extinguished in less than one minute, and all of the obstructed fires 2.0 MW or larger would be extinguished in less than three minutes and thirty seconds. These extinguishment times were based on fires produced using heptane as the fuel and should be significantly less for typical Navy fuels (i.e. F76). It was also shown that fires requiring a longer time to extinguish can be easily approached and extinguished using a standard Navy portable extinguisher. This prototype system (nozzles and system design) has been validated for use in the machinery spaced on the LPD-17.

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FULL-SCALE MACHINERY SPACE WATER MIST TESTS: FINAL DESIGN VALIDATION

1.0 INTRODUCTION

The U.S. Navy is conducting an ongoing investigation into the use of water mist as a replacement for Halon 1301 total flooding systems which are currently installed in shipboard machinery spaces. The initial design and development of the machinery space water mist system was determined during two, previously conducted, full-scale test series [1, 2]. These two series were conducted in a simulated machinery space located onboard the ex-USS SHADWELL in Mobile, AL [3].

The initial investigations were conducted in both an empty machinery space and a machinery space fitted with mockups of equipment typically installed in these spaces (i.e., combustion engines, reduction gears and ductwork). The fire threats consisted of combinations of fuel spray and pan fires positioned at various locations throughout the space. The estimated total heat release rates of these fire scenarios ranged from 2.5 to 7.5 MW. Initially, the water mist system consisted of nozzles installed at one level in the overhead of the space. To improve system performance, the nozzles were installed on two levels as is the current practice with the Halon 1301 total flooding systems. The system exhibiting superior firefighting capabilities was a system developed using commercially available off-the-shelf industrial spray nozzles produced by Spraying Systems Company. The system developed using these nozzles was capable of extinguishing all of the unventilated fire scenarios in less than twenty five seconds of system activation and used less than 100 L (25 gal) of water. Based on these results, this nozzle was selected to be incorporated in the design and development of a water mist system for future Navy machinery space applications.

During a recent investigation [4], the nozzle was redesigned to increase its durability and potentially increase its firefighting capabilities. Based on the results of the initial full-scale test programs and scoping tests conducted at the Naval Research Laboratory's (NRL) Chesapeake

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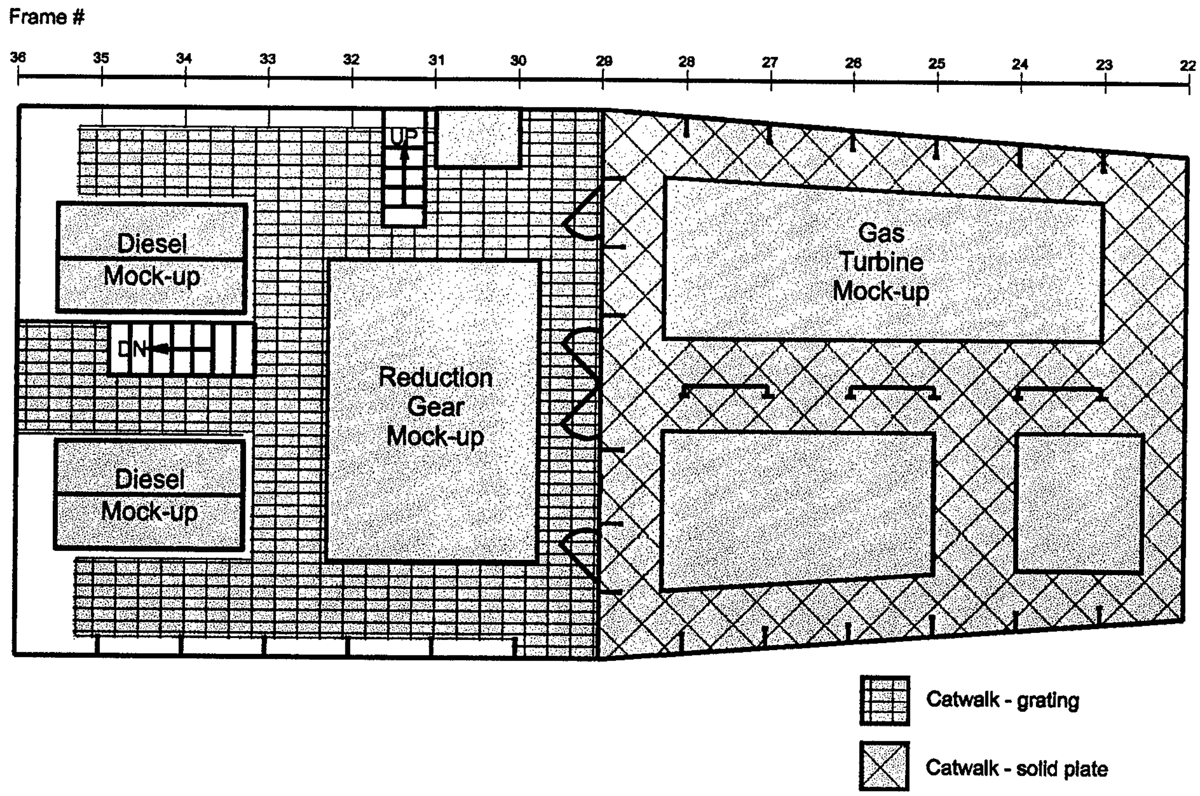
Beach Detachment (CBD), a preliminary water mist system design was developed. During this investigation, the fire fighting capabilities of the new system and system design parameters were validated. The design validation tests, discussed in this report, were conducted on the ex-USS SHADWELL during November 1996 in accordance with the approved test plan [5].

2.0 OBJECTIVES

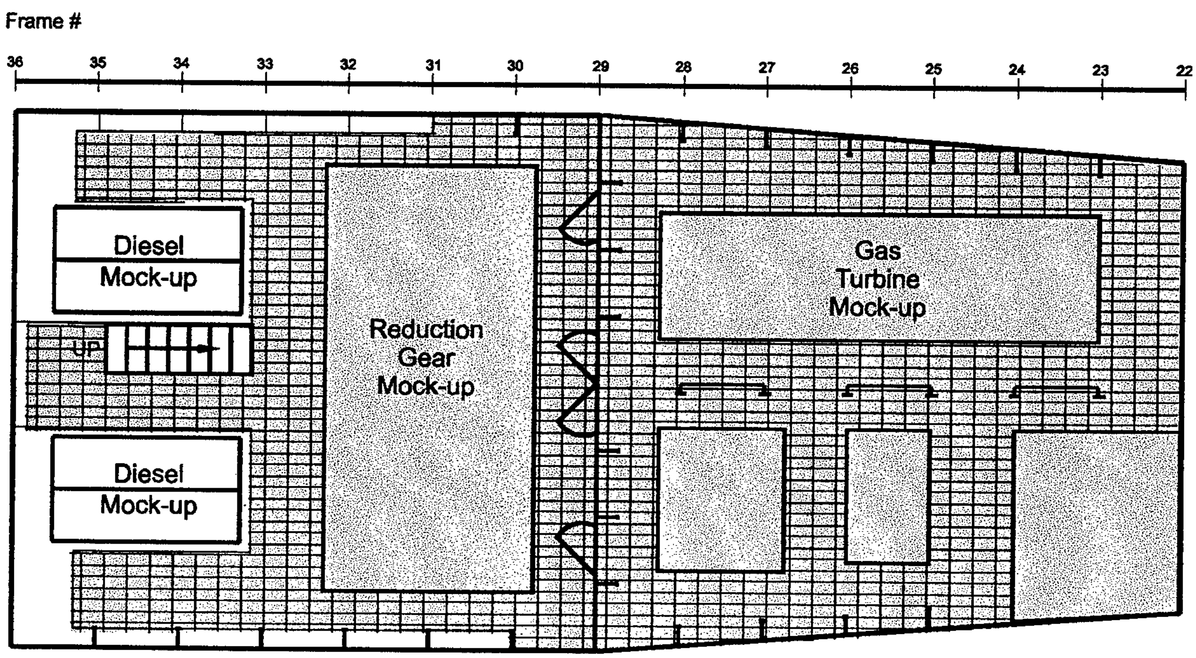
The overall objective of this effort was to develop an environmentally acceptable replacement for Halon 1301 for new ships, starting with LPD-17. This investigation focused primarily on evaluating and refining the firefighting capabilities of a prototype water mist system. During this evaluation, the firefighting capabilities of the water mist system with respect to fire size and the degree of fire obstruction were identified. An assessment of water mist system design parameters was also conducted in an attempt to optimize the firefighting capabilities of the system and to further refine the proposed design criteria. The various functional aspects of the water mist system components (i.e., pumps, valves and nozzles) were evaluated in a separate investigation.

3.0 TEST COMPARTMENT

The tests were conducted on the ex-USS SHADWELL in the machinery space used during the previous full-scale investigations [1, 2]. The space was located between Frames 22 and 36 and includes the fourth and fifth decks (Figure 1). The space was approximately 9 x 18 x 6 m (30 x 60 x 20 ft), producing a total volume of 972 m^3 (36,000 ft^3). Included in this space was the ships' bilge approximately 0.7 m (2.3 ft) deep and two levels of catwalks. The space was fitted with sheet metal mock-ups of typical machinery space equipment as shown in Figures 2 and 3. Eight water-tight doors, four on each level, were installed in the bulkhead located at FR 29 to allow the isolation of the forward half of the compartment to evaluate the effects of compartment volume on the extinguishment capabilities of the system.



Machinery space with mock-ups - Fourth Deck



Machinery space with mock-ups - Fifth Deck

Fig. 1 – Machinery space deck configurations (plan views)

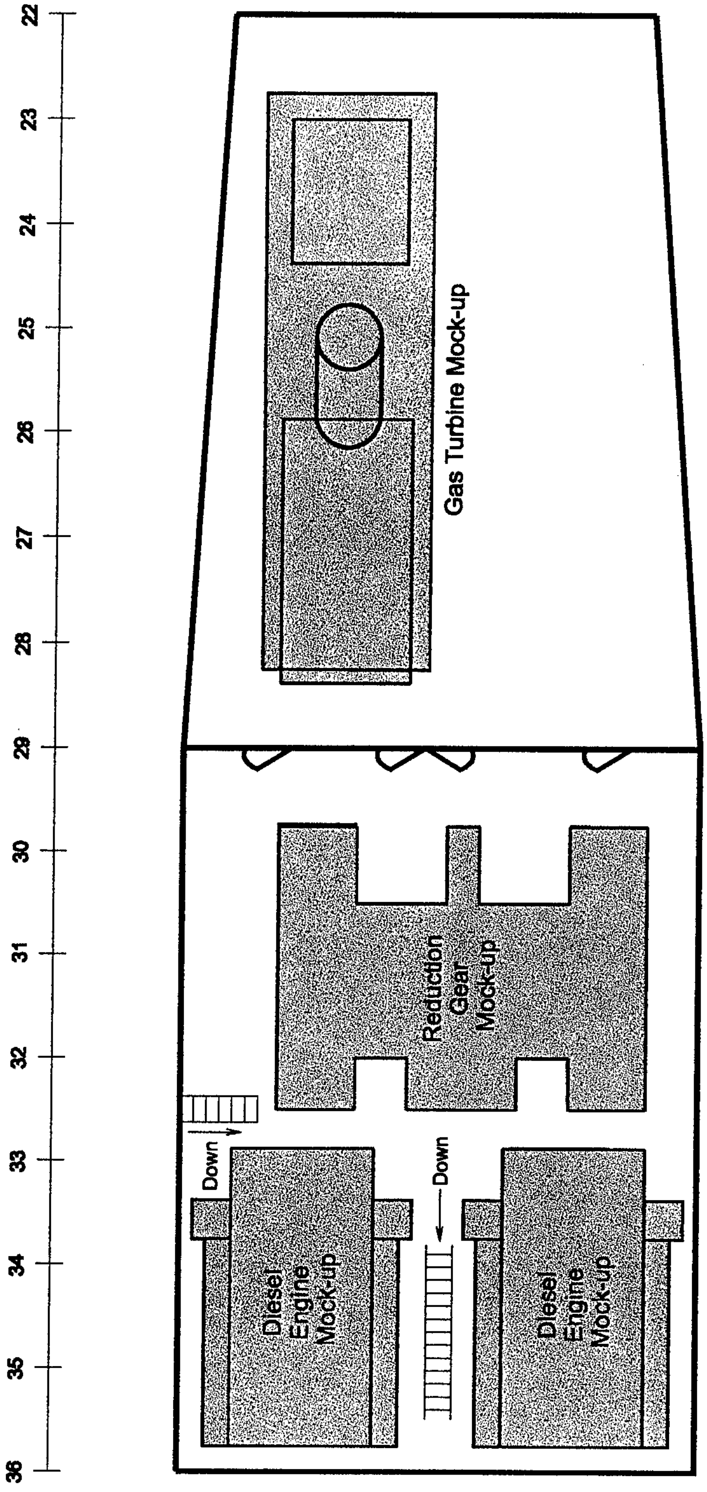


Fig. 2 – Machinery space equipment configuration (plan view)

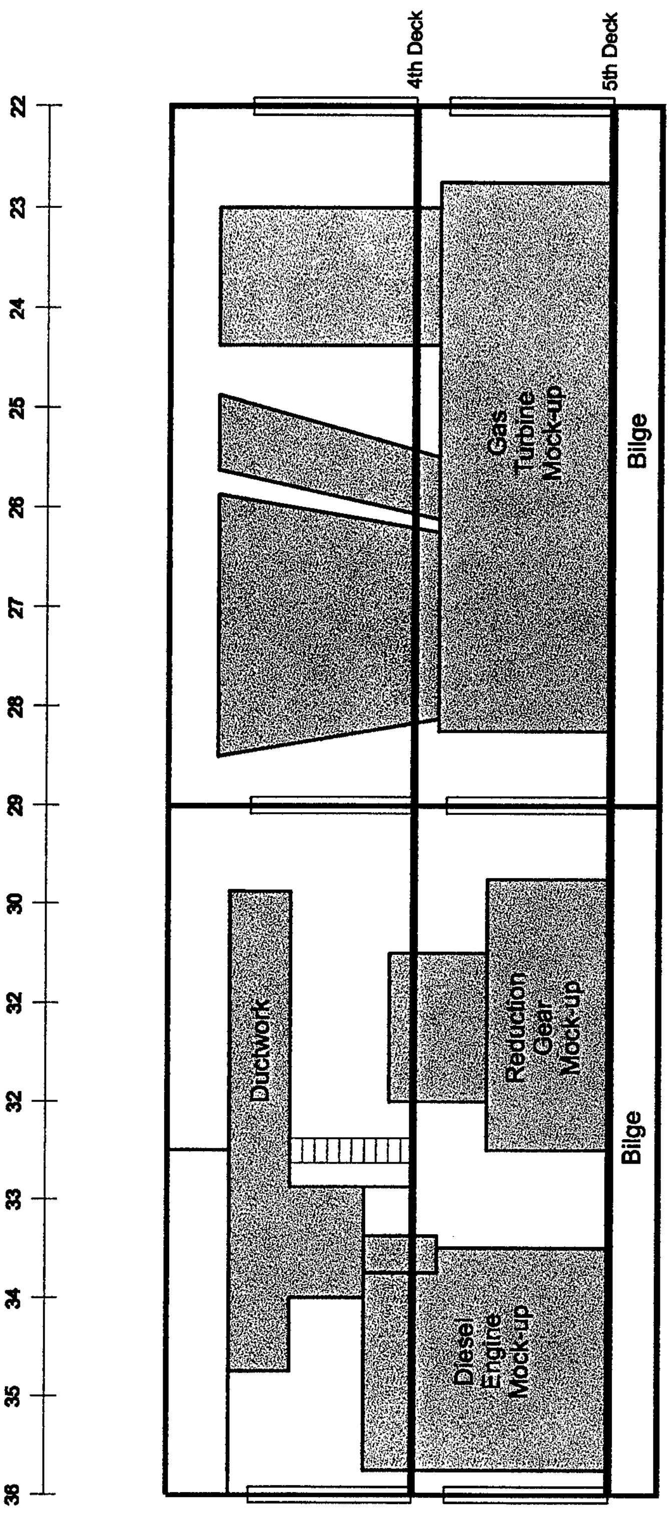


Fig. 3 – Machinery space equipment configuration (elevation view)

4.0 WATER MIST SYSTEM

4.1 Water Mist Nozzles

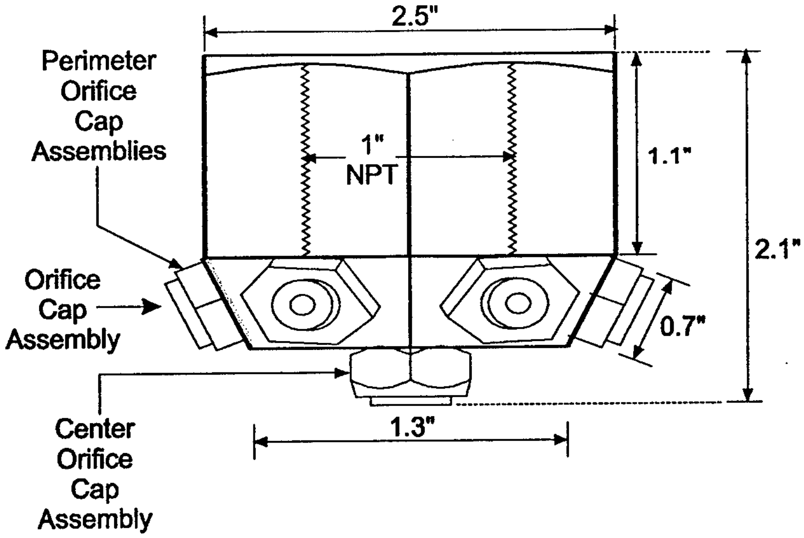
A total of six single-fluid, high-pressure nozzle configurations were evaluated during this investigation. These nozzles were evaluated at a pressure of 70 bar (1000 psi). Each of the six nozzles consisted of a Spraying Systems Model 7N nozzle body with seven Model 1/4LN orifice cap assemblies (orifice cap and orifice insert) (Figure 4). Various combinations of orifice caps and orifice inserts were evaluated. Varying the orifice cap configuration adjusted the spray characteristics of the nozzle (i.e., k-Factor spray pattern, drop size and spray momentum) [4]. The orifice cap assemblies will be referred to using the following nomenclature: "1.5 w 26" where 1.5 is the orifice cap size (CP 1206 and CP 1207-1.5) and the 26 is the orifice insert size (CP 7284-26).

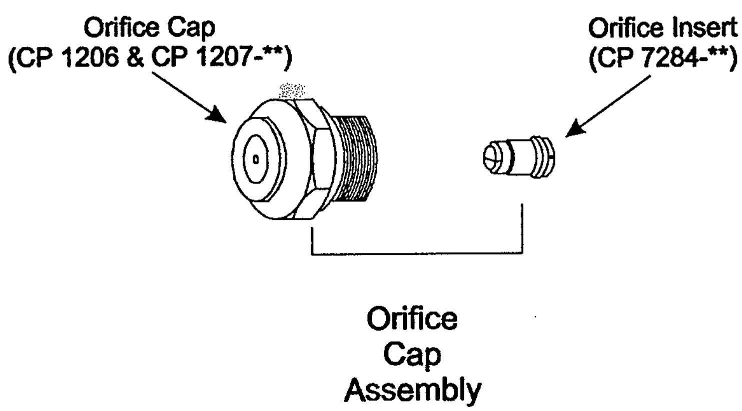
It was originally intended to adjust the spray patterns of each nozzle to fit the area being protected. This approach would increase the amount of mist in the space by minimizing the mist lost due to spray impingement on surfaces near the nozzles (plate losses). This approach was abandoned due to the added complexity of the design. In short, it was easy to develop the logic to reduce the flow rate/orifice size of a nozzle located near obstructions, but it was much more difficult to develop generic guidelines of how and where to add the mist back into the space. It was estimated that 25 percent of the water discharged by the system did not contribute to the concentration of mist in the space due to plate losses.

4.2 Water Mist Pipe Network

The water mist system design is shown in Figures 5 and 6. The design consisted of 40 nozzles installed at two levels (at the overhead of the fourth and fifth decks) with nozzle locations staggered between levels. The design was based on a nominal 3.0 m (10 ft) nozzle spacing. The individual nozzle positions were determined based on the characteristics (i.e.,

Spraying Systems Model 7N Nozzle Body

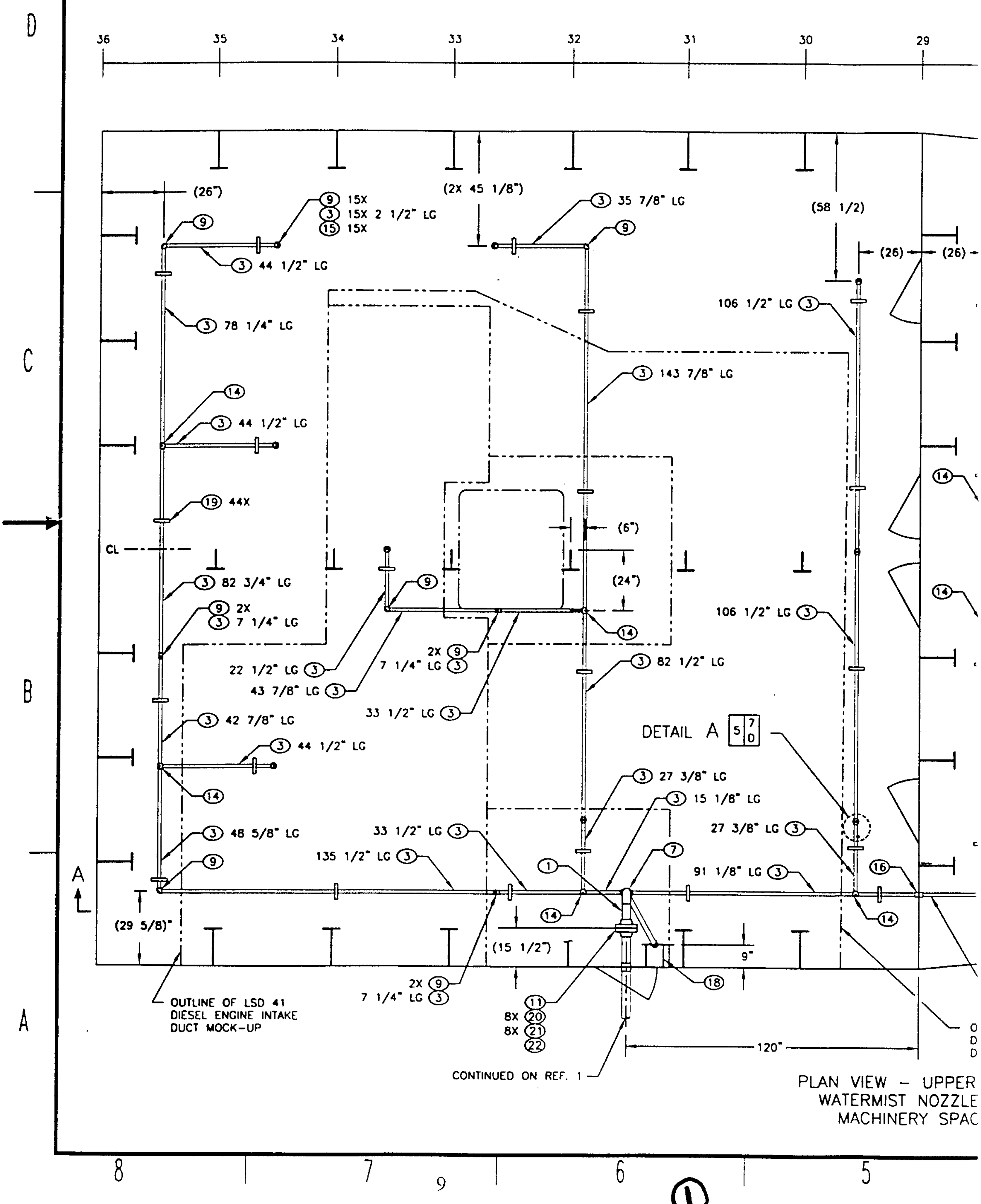




*Note: ** are size designations*
For example, a "1.5 x 26" consists of a CP1206, CP1207-1.5 and a CP7284-26

Fig. 4 – Water mist nozzle

Fig. 5 - Water mist system nozzle locations (fourth deck)



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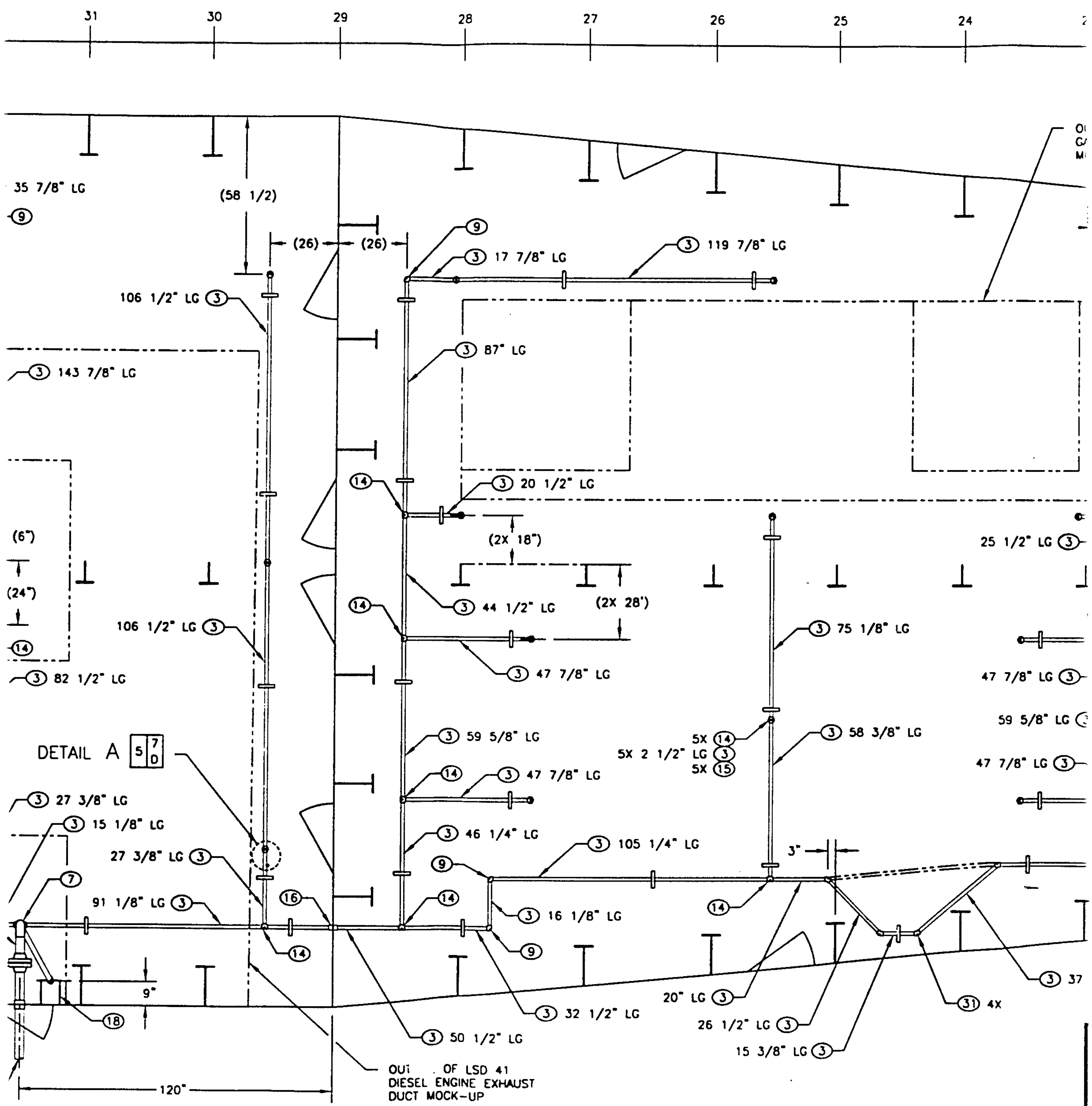

PLAN VIEW – UPPER LEVEL FR 22–36
WATERMIST NOZZLE ARRANGEMENT
MACHINERY SPACE 4-22-0-E

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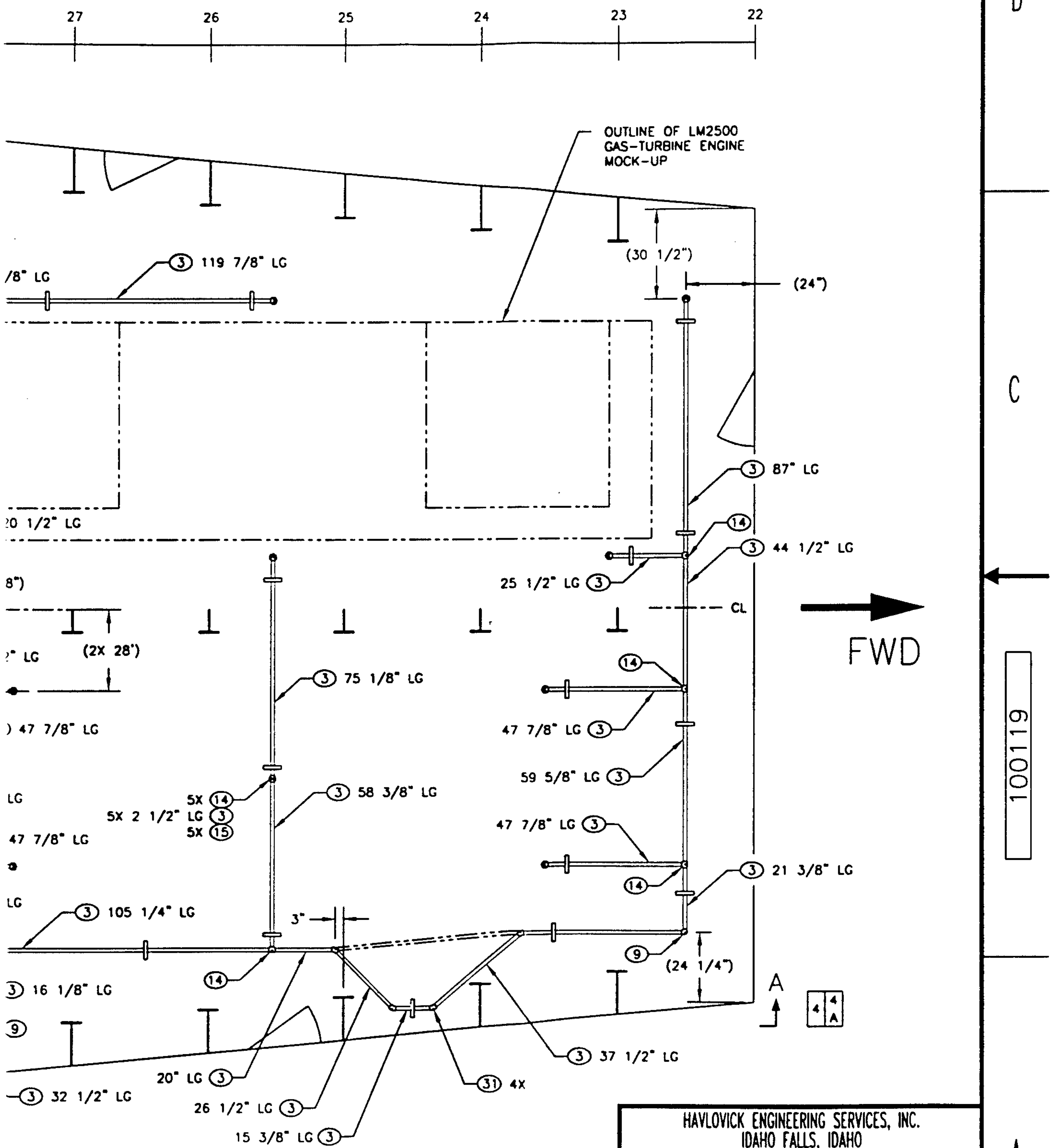

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HAVLOVICK ENGINEERING SERVICES, INC.
IDAHO FALLS, IDAHO

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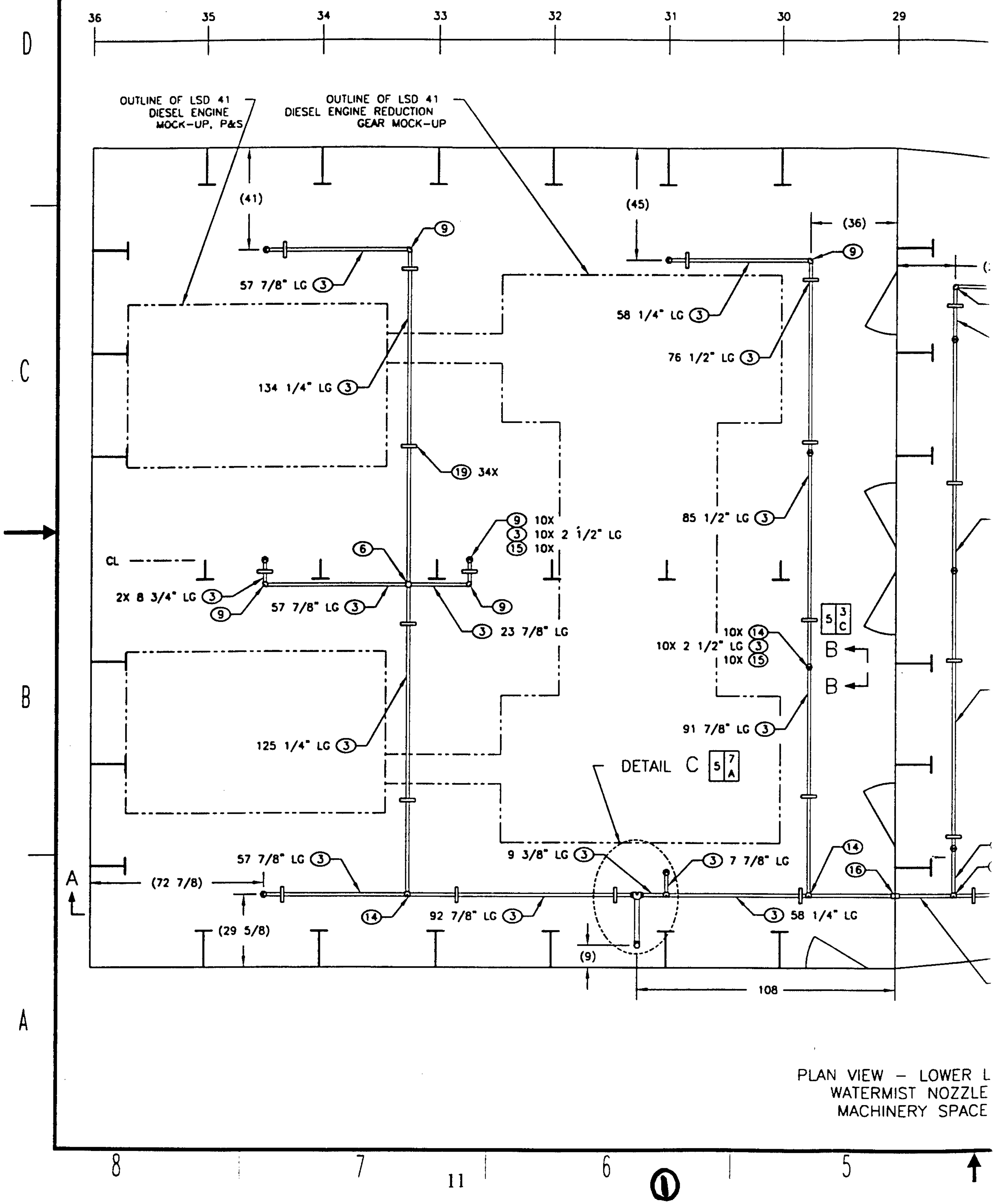
Fig 6 - Water mist system nozzle locations (fifth deck)



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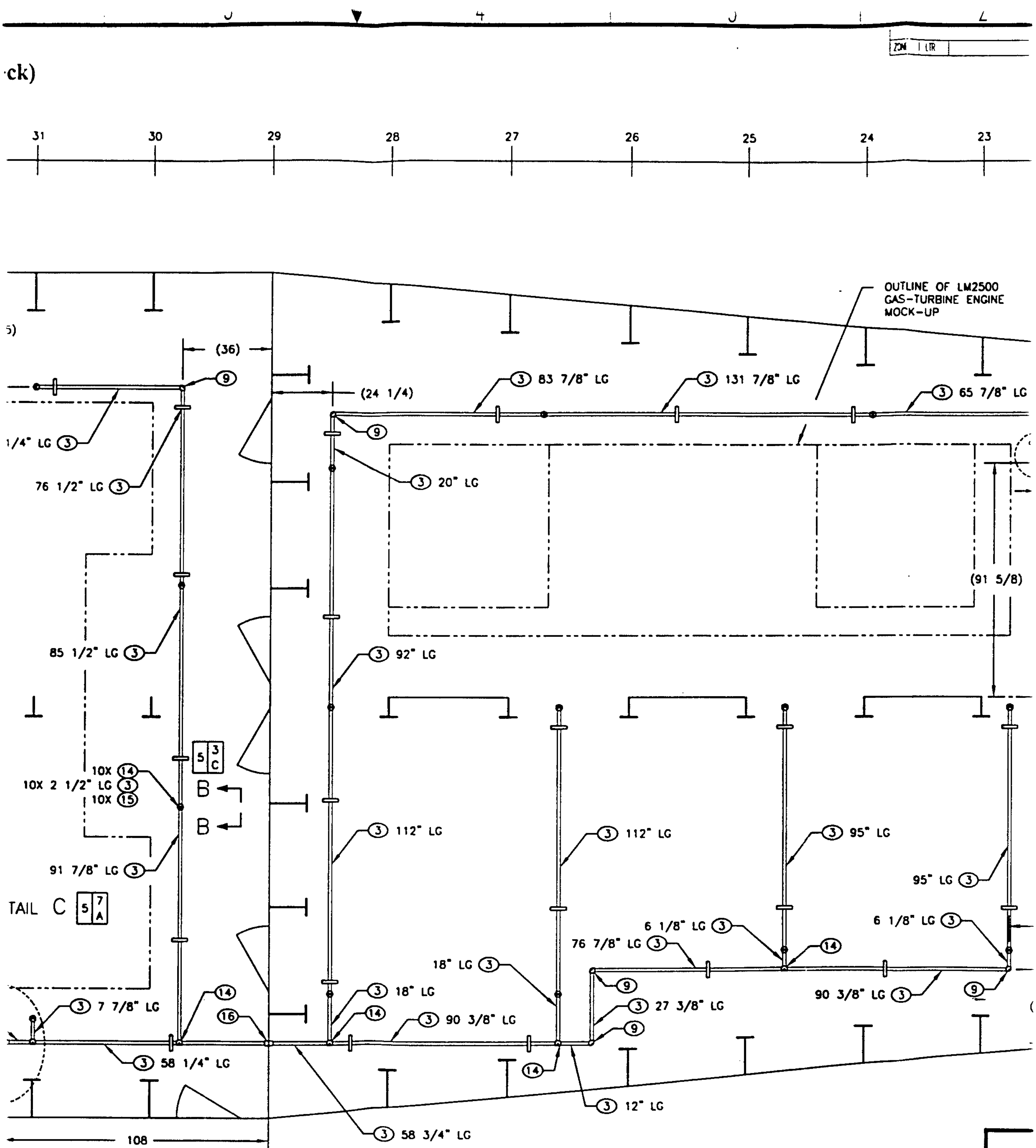

PLAN VIEW – LOWER LEVEL FR 22-36
WATERMIST NOZZLE ARRANGEMENT
MACHINERY SPACE 4-22-0-E

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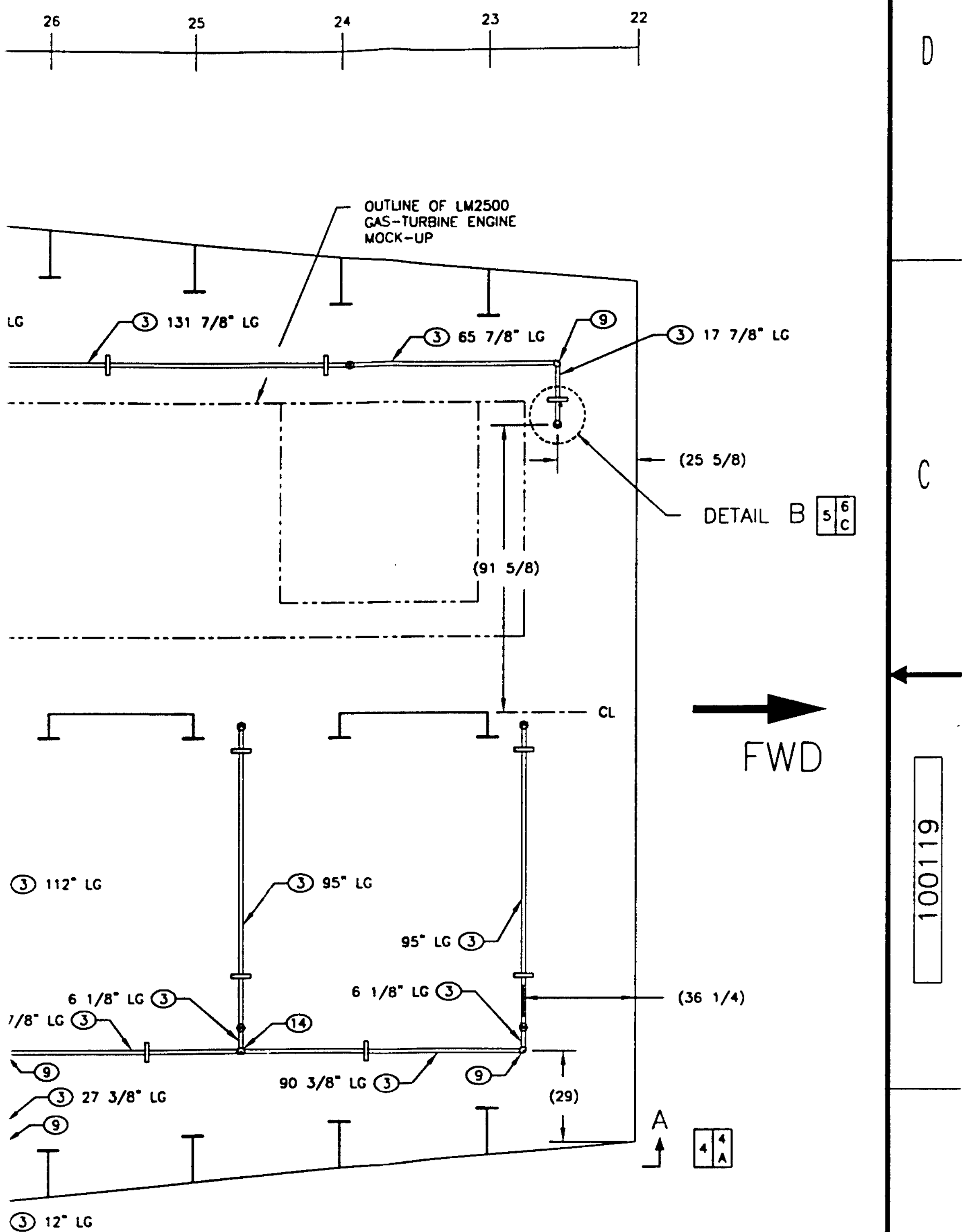

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NOZZLE & DIST PIPE ADDITION,
WATERMIST TEST SYSTEM,
MACHINERY SPACE FIRE TESTS,
ex-USS SHADWELL

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obstructions) of the area being protected. Based on the results of previous tests [1,2], the water mist system was designed to produce a flow rate per unit volume of 0.4 Lpm/m^3 (0.003 gpm/ft^3).

The system was produced using MIL SPEC components where possible. The system was constructed primarily of 7.6, 3.8 and 2.5 cm (3, 1.5 and 1 in.) stainless steel piping (AISI 304). Connections consisted of welded stainless steel fittings. Approximately 35% of the 7.6 cm (3 in) welded joints underwent radiographic examination. As designed, this system had a working pressure of 207 bar (3000 psi) and a burst pressure of 827 bar (12,000 psi).

4.3 Water Mist Pump Package

The pump incorporated in the system was designed to protect the main and auxiliary machinery spaces on the LPD-17. The pump was designed to flow 850 Lpm (225 gpm) at an operating pressure of 70 bar (1000 psi). During these tests, the pump operated at 70 bar (1000 psi) and flowed 340 Lpm (90 gpm) into the space. The remainder of the flow (510 Lpm (135 gpm)) was recirculated back into the supply tank.

The water mist pump package was located in the ex-SHADWELL's starboard engine room (4-64-1). A schematic of the system is shown in Figure 7.

The water mist pump was a positive displacement piston pump manufactured by Wheatley Pumps, Inc. (Model HP-200L). The pump was supplied with potable water from a storage tank (16,654 L (4,400 gal)) located on the third deck between frames 64 and 67. The pump was driven by a MIL-SPEC 200 hp 440 VAC electric motor manufactured by Reliance Electric, Inc. A drawing and photograph of the pump is shown in Figure 8. The motor was controlled using a MIL-SPEC motor controller (S.N.1ZZNO5988A 1 NZ) connected directly to one of the diesel generators located on the main deck. A commercial pressure relief valve manufactured by Baird Manufacturing Co. (P.N 762-7601-2-505 MP) was installed in a bypass line to prevent over pressurization of the system. The relief valve was set to 96 bar (1400 psi).

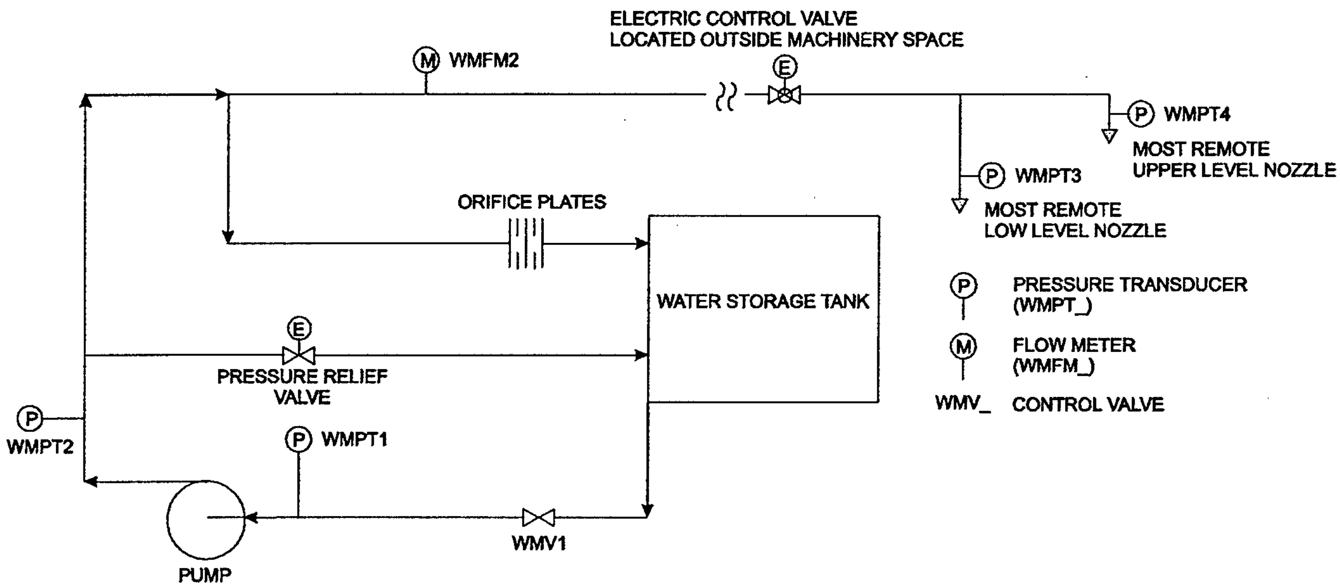


Fig. 7 – Water mist pump package schematic

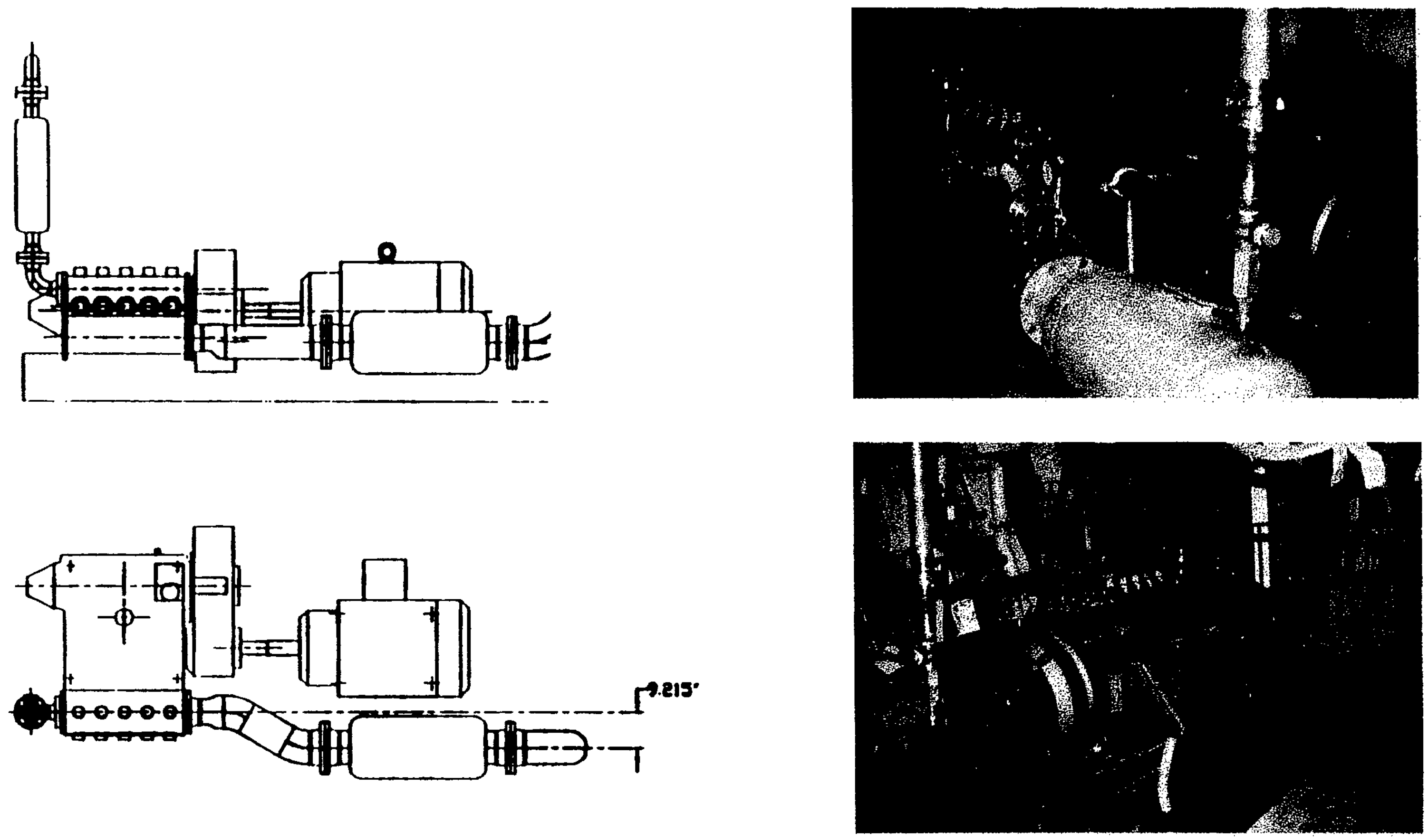


Fig. 8 – Water mist pump assembly

During mist system activation, the control valve (WMV5B) located outside the test compartment was opened two seconds prior to pump startup.

5.0 FIRE SCENARIOS

The fire scenarios were designed to identify the firefighting capabilities of the system with respect to fire size, fire location and the degree of fire obstruction. The fire locations are shown in Figure 9. Fire Location #1 was on the fifth deck in the center of the space. Horizontal obstructions were installed above this location (1.5 m (5 ft)) to make these fires more difficult to extinguish. These obstructions were square steel plates (6 mm (0.25 in.) thick) and ranged in size from 1-3 m (3.3-10 ft) on a side. Fire Location #2 was unobstructed and located high in the space (above the lower level of nozzles) positioned between four nozzles in the upper grid. Fire Location #3 represented a highly shielded/cluttered location forward in the space on the lower level. During some of the tests, the water mist nozzles above Fire Location #3 were removed to produce a worst case scenario where very little mist reached the fire.

The fire scenarios consisted primarily of heptane spray fires of various sizes although a typical Navy fuel (F76) was evaluated later in the test series. Heptane was selected because it is difficult to extinguish due to its low flashpoint and because it allows visual observation of the test due to low smoke production. The spray fires were produced using "P" series nozzles manufactured by Bete Fog Nozzle, Inc. These nozzles were oriented vertically upward and provided with fuel using a pressurized fuel source located in the well deck of the ship.

The initial set of tests evaluated the firefighting capabilities of six water mist nozzle designs installed with identical nozzle spacings. From these tests, one nozzle/system was selected for further evaluation. A second set of tests was conducted to identify the firefighting capabilities of the selected system with respect to the fire size. This was accomplished by evaluating the system against a wide range of spray fire sizes (0.5 to 5.0 MW). These tests were conducted at various locations in the compartment. A selected number of these fires were

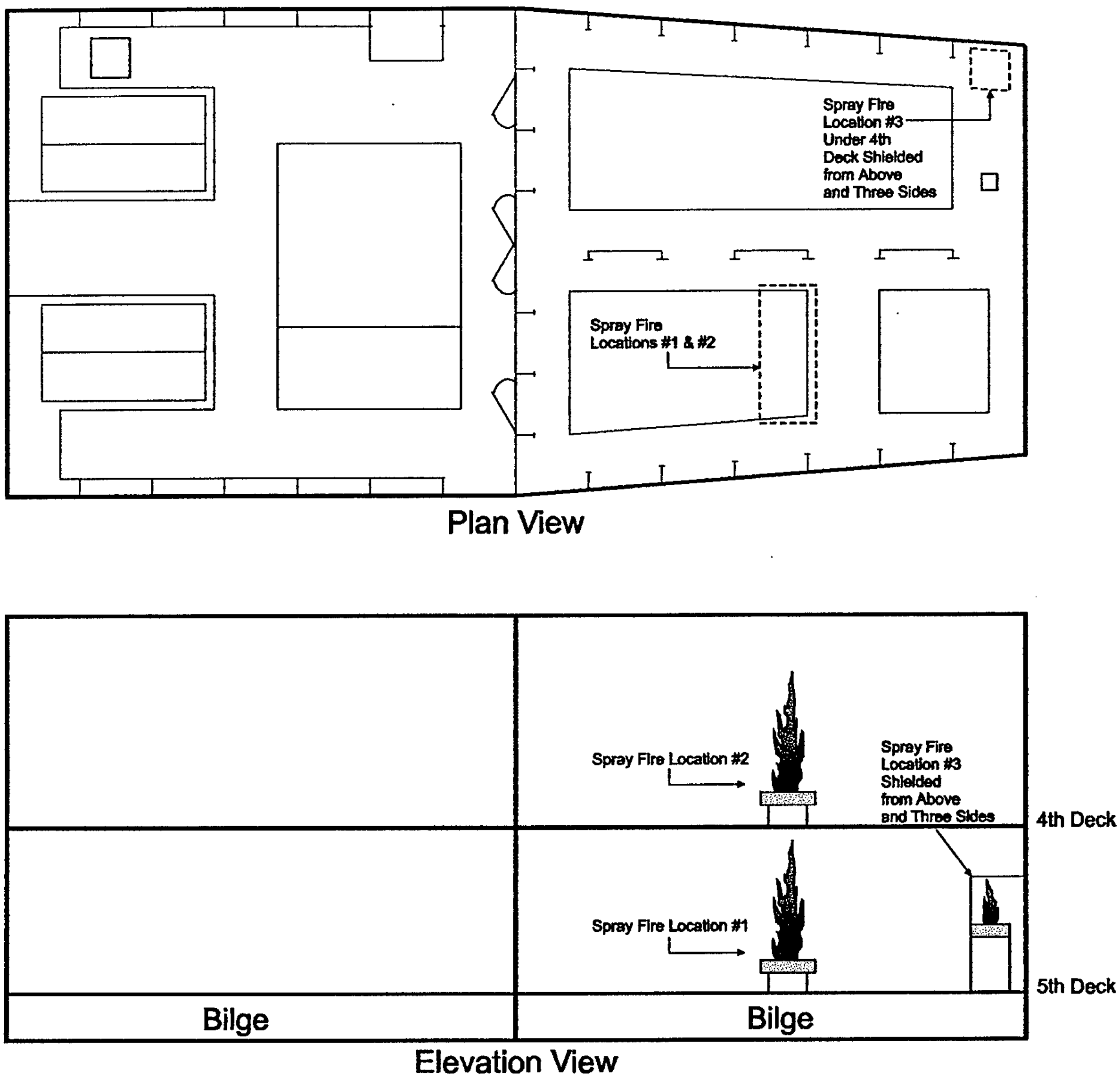


Fig. 9 – Fire Locations

repeated using F76 to quantify the effects of different fuels (i.e., different flashpoints). A third set of tests evaluated the ability of the system to extinguish obstructed fires. Horizontal obstructions ranging from one to three meters were used. During these tests, the effect of preburn time on extinguishment was also determined. Additional tests were conducted to evaluate various potential failure modes associated with water mist systems in general. These modes consisted of a reduction in system pressure resulting from damage to the pipe network and increased ventilation in the space (natural only). Forced ventilation was evaluated during the previous two investigations [1,2]. The final set of tests (Reduced volume) provided information pertaining to scaling the results to the larger machinery spaces on the LPD-17 (2-2.5 times the test volume). These tests were conducted in the forward half of the space with the water-tight doors at FR29 closed.

6.0 INSTRUMENTATION

The instrumentation scheme used during the previous full scale test series [1, 2] was used during this evaluation. The space was instrumented for temperature, radiant and total heat flux, and typical fire gas species (O_2, CO and CO_2) as shown in Figure 10. The water mist system was instrumented to measure the system operating pressure and water flow rate.

6.1 Temperature Measurements

Inconel-sheathed Type K, thermocouples (1.6 mm (0.06 in.) dia.) were used to measure the air and fire temperatures during these tests.

The air temperatures in the machinery space were measured using four thermocouple trees. The trees were located at 5-22-1, 5-27-1, 5-27-2 and 5-35-1, as shown in Figure 10. Each thermocouple tree consisted of six thermocouples positioned 0.3 m, 1.2 m , 2.1 m, 3.0 m, 3.9 m and 4.8 m (1 ft, 4 ft, 7 ft, 10 ft, 13 ft and 16 ft) above the fifth deck.

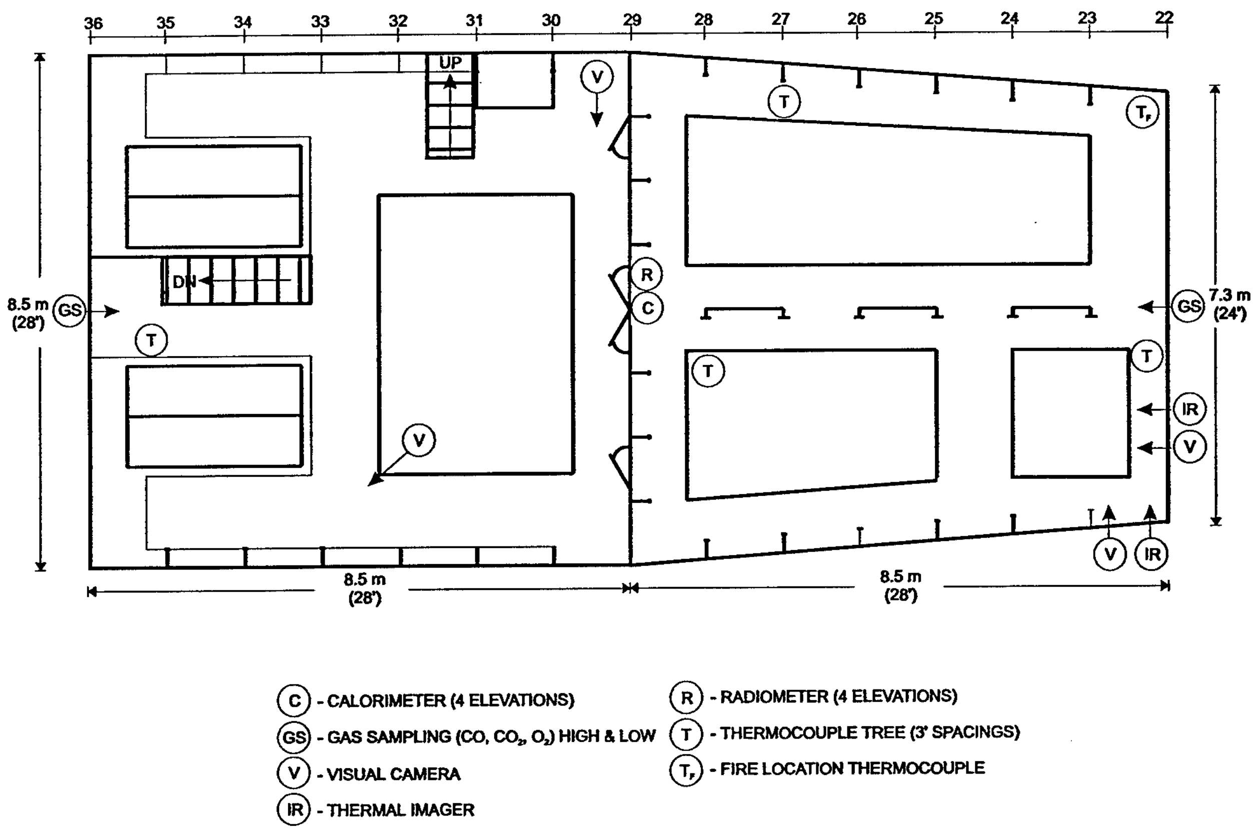


Fig. 10 – Machinery space instrumentation

Thermocouples were installed at each of the fire locations to determine the fire extinguishment times. These fire locations are shown in Figure 9. Two thermocouples were installed at Location #1 above the fuel spray nozzle, below the fourth deck. Two thermocouples installed near the overhead of the fourth deck were used to monitor Fire Location #2. The two thermocouples were installed above the fuel spray nozzle (0.9 m (3 ft) at Fire Location #3.

Thermocouples were also used to record the ambient air temperature, the water mist pump room air temperature and the temperature of the water being supplied to the water mist pump.

6.2 Gas Concentration Measurements

Continuous gas concentration measurements were made for oxygen, carbon dioxide and carbon monoxide. Concentrations were measured along centerline of the space at FR 22 and FR 36. The sampling ports were located 0.5 m (1.5 ft) and 3.9 m (12.7 ft) above the fifth deck. The gas concentration measurements were made using Rosemount Model NGA 2000 gas analyzers. Prior to reaching the analyzers the gas samples were dried and filtered.

6.3 Heat Flux Measurements

Calorimeters and radiometers were installed to measure total and radiant heat fluxes at four elevations at FR 29 near the centerline of the space. Instruments were positioned 0.9 m, 2.3 m, 3.8 m and 5.3 m (3 ft, 7.5 ft, 12.5 ft and 17.5 ft) above the fifth deck, facing forward. These instruments were water cooled and had a full-scale range of 0-57 kW/m^2 (0-5 $Btu/ft^2 \cdot s$).

6.4 Pressure Measurements

The operating pressure of the water mist system was measured at several locations. The pressure was measured in the water mist pump room (4-69-1) and at two locations in the test compartment (4-29-1 and 5-22-2). These pressures were measured using Setra Model 280E

transducers with a full-scale range of 0 - 207 bar (0 - 3000 psi). The suction pressure was measured in the pump room (4-67-1) using a Setra Model 280E transducer with a range of -1.0 - 2.4 bar (-14.7 - 35 psi). The water level of the storage tank was monitored using a Setra Model 280E transducer located in the bottom of the tank (4-65-1). This transducer had a range of 0-1.0 bar (0 - 15 psi).

6.5 Water Flow Rate Measurements

Ultrasonic flowmeters (Controlotron 9000 series) were installed to measure the flow to the machinery space (4-66-1) and the bypass flow back to the water storage tank (4-64-1). These ultrasonic flowmeters have an adjustable range, which was set at 0 - 1136 Lpm (0 - 300 gpm) for this test series.

6.6 Video Coverage

Both infrared and visual cameras were used during this evaluation. Infrared cameras were positioned to monitor Fire Locations #1, #2 and #3 (5-22-1, 4-28-0 and 5-22-3 respectively). Visual cameras were positioned at 5-22-1 and 5-22-3 to monitor Fire Locations #1 and #3. A visual camera was installed to monitor test team personnel (5-29-2). A visual camera was installed to monitor the discharge from a water mist nozzle (5-32-1). Another visual camera was located in the water mist pump room to monitor test team members located in that area.

7.0 PROCEDURES

The tests were initiated from the control room located on the 02 level. All key personnel were located in the control room during each test with the exception of the safety officer and a firefighter located inside the test compartment. The data acquisition system was activated two minutes prior to ignition marking the start of the test. The fires were allowed to burn freely for one minute before mist discharge. Due to the time required to fill the pipe network, the mist

system had to be activated thirty seconds after ignition for water to be discharged into the space one minute after ignition. This thirty second delivery time was reduced to eight seconds during the water mist system flow tests conducted later in the year. The mist system remained activated until the fire was extinguished. After the test was completed, the limited protection exhaust and supply systems were activated to clear the space of mist and combustion gases. The space remained off-limits until cleared by the safety officer and the test director.

8.0 RESULTS AND DISCUSSION

Over 60 full-scale fire tests were conducted during this evaluation. These tests are discussed in subsequent paragraphs relating the results to the specific objectives of the tests. A complete set of test data is found in Appendix A. The results of these tests will be described in terms of preburn time, extinguishment time and fire burn time. These terms are defined as follows:

- Preburn time is the time the fire burns prior to mist discharge.
- Extinguishment time is the time required to extinguish the fire measured from the start of mist discharge (70 bar (1000 psi)) nozzle pressure).
- Fire burn time is the total time the fire burned, and is the sum of the preburn time and the extinguishment time.

8.1 System Optimization/Nozzle Selection

The firefighting capabilities of six water mist nozzle designs were evaluated against three (1.0, 2.5 and 5.0 MW) obstructed (1 m^2 (10.8 ft^2)) heptane spray fires during the initial set of tests. A description of each nozzle arrangement is found in Table 1. The results of these tests are summarized in Table 2. Included in Table 2 are the fire extinguishment times measured from the start of mist discharge, the average oxygen concentration in the space at extinguishment and the steady-state compartment temperature measured just prior to extinguishment.

Table 1. Water Mist System/Nozzle Orifice Cap Configurations

System	Upper Level Nozzles		Lower Level Nozzles		System Flow Rate Lpm (gpm)	Percent of Water Discharged	
	Perimeter	Center	Perimeter	Center		Upper Level Nozzles	Lower Level Nozzles
1	1.5w26	18w18	1.5w26	2w2	360 (95)	55	45
2	1.5w26	1.5w26	1.5w26	2w2	275 (73)	55	45
3	1.5w26	2w26	1.5w26	2w2	290 (77)	55	45
4	2w26	4w4	1.5w26	2w2	335 (86)	60	40
5	2w26	4w26	1.5w26	2w2	305 (81)	62	38
6	2w26	12w12	1.5w26	2w2	320 (85)	67	33

Table 2. System/Nozzle Comparison Test Results

Test #	Fire Size	Fire Location	Mist System	Compartment Configuration	Extinguishment Time* (min:sec)	Oxygen Concentration at Extinguishment ** (%) Dry	Steady-state Compartment Temperature *** (°C)
2	5.0 MW	#1	#1	Full	0:53	16.5	50
4	2.5 MW	#1	#1	Full	1:45	16.0	46
6	1.0 MW	#1	#1	Full	2:50	17.0	43
8	5.0 MW	#1	#2	Full	1:44	15.0	50
9	5.0 MW	#1	#2	Full	1:00	15.0	50
11	2.5 MW	#1	#2	Full	2:04	16.0	45
13	1.0 MW	#1	#2	Full	4:28	16.0	45
15	1.0 MW	#1	#3	Full	3:03	16.0	45
16	2.5 MW	#1	#3	Full	1:18	17.0	48
17	5.0 MW	#1	#3	Full	0:31	16.0	50
21	1.0 MW	#1	#4	Full	4:29	17.0	45
22	2.5 MW	#1	#4	Full	1:20	16.0	48
23	5.0 MW	#1	#4	Full	0:50	16.0	52
24	5.0 MW	#1	#5	Full	0:34	16.0	50
26	2.5 MW	#1	#5	Full	1:06	17.0	47
28	1.0 MW	#1	#5	Full	3:54	17.0	44
30	5.0 MW	#1	#6	Full	0:40	16.0	50
31	5.0 MW	#1	#6	Full	0:33	16.0	50
32	2.5 MW	#1	#6	Full	0:53	18.0	48
33	1.0 MW	#1	#6	Full	2:55	17.0	45

* Extinguishment times were measured from mist discharge.

** Oxygen concentrations shown in the table are the average of the four measurements recorded during the test.

*** The steady-state compartment temperature is defined as the uniform compartment temperature reached just prior to extinguishment.

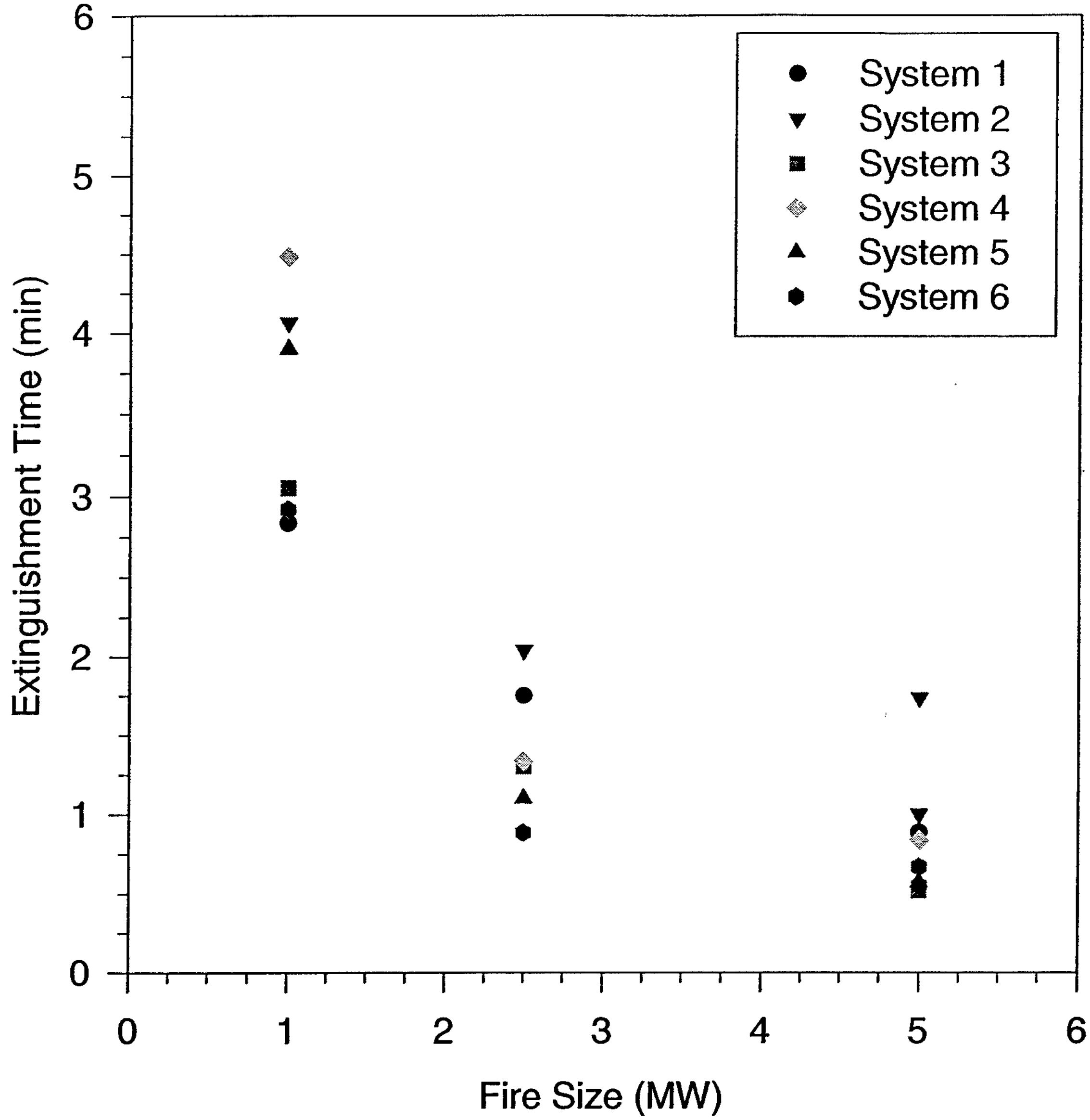
The extinguishment times for the six systems are plotted in Figure 11 as a function of fire size. All six systems were capable of extinguishing the three heptane spray fires included in this evaluation. As found throughout the literature, the larger fires were extinguished faster than the smaller fires. On average, the six systems were capable of extinguishing the 5.0 MW fire in less than one minute, the 2.5 MW fire in approximately one minute and thirty seconds and the 1.0 MW fire in approximately three minutes and thirty seconds.

Throughout these tests, System #6 provided the best overall performance for the fire scenarios tested. This system consisted of high flow nozzles installed in the upper level grid (overhead fourth deck) and low flow nozzles installed in the lower level grid (overhead fifth deck). The flow rate of the upper level nozzles (13.2 Lpm (3.5 gpm)) was approximately twice that of the lower level nozzles (5.7 Lpm (1.5 gpm)). Based on the extinguishment capabilities of the system, it can be assumed that this design provided the best mixing and the most uniform mist distribution of the six systems evaluated. The specific orifice arrangements for the upper and lower nozzles are shown in Table 1.

8.2 System Capabilities

The fire extinguishing capabilities of System #6 were evaluated against a variety of heptane spray fire sizes, fire obstructions and fire locations. The fire locations are shown in Figure 9. The results of these tests are summarized in Table 3.

The extinguishment times for the fire obstruction evaluation are plotted in Figure 12 as a function of fire size. The net result is a family of curves illustrating the effect of the degree of fire obstruction on extinguishment time. When the fires were located in an area of high mist concentration (i.e., unobstructed), the fires were quickly extinguished (≈ twenty seconds) with the extinguishment time relatively unaffected by the size of the fire. The extinguishment times of these fires appear to be primarily dependent on the time required to deliver sufficient mist to the fire location. As the size of the obstruction was increased, the amount of mist reaching the fire decreased and the extinguishment of these fires became more dependent on oxygen depletion



Heptane spray fires
Fire location #1
1.0 m (3.3 ft) horizontal obstruction

Fig. 11 – System/nozzle comparison

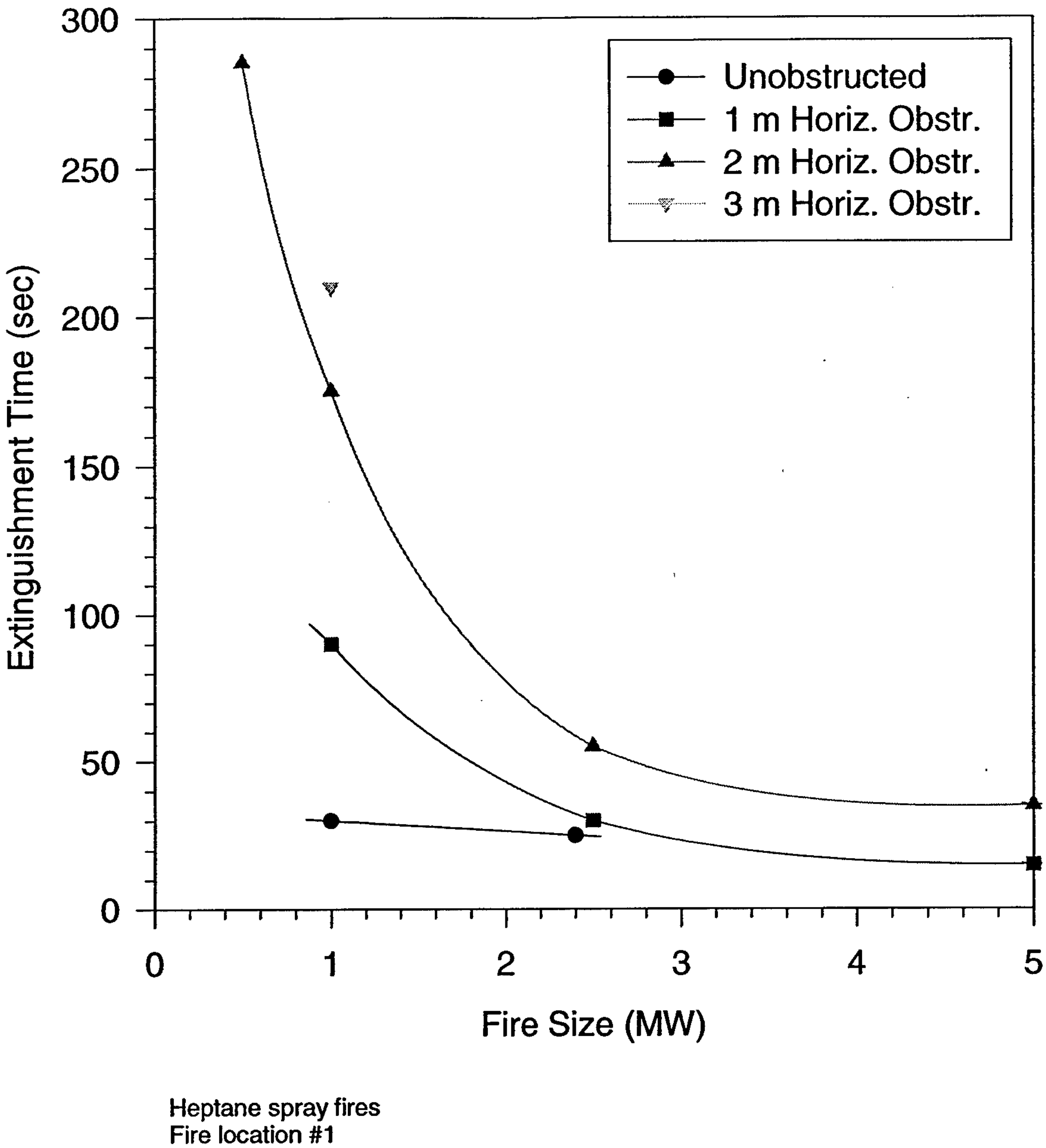


Fig. 12 – Fire extinguishing capabilities as a function of horizontal obstruction size

and less dependent on mist concentration. The net oxygen depletion is a result of both the consumption of oxygen by the fire and the dilution of oxygen by water vapor (steam). The extinguishment times for fires that required some degree of oxygen depletion for extinguishment behaved exponentially as the fire size was reduced. All of the obstructed fires independent of the size of the obstruction produced this trend in extinguishment times. The larger fires quickly reduced the oxygen concentrations in the space, making the differences in extinguishment times between larger fires less pronounced.

Table 3. System Capabilities (System #6)

Test	Fire Size	Fire Location	Obstruction Size (m)	Compartment Configuration	Extinguishment Time (min:sec)	Oxygen Concentration at Extinguishment (%) Dry	Steady-state Compartment Temperature (°C)
30	5.0 MW	#1	2	Full	0:40	16	50
31	5.0 MW	#1	1	Full	0:33	16	50
32	2.5 MW	#1	2	Full	0:53	18	48
33	1.0 MW	#1	2	Full	2:55	17	45
34	1.0 MW	#3	0	Full	0:24	19	40
35	1.0 MW	#3	3	Full	3:30	16	40
36	5.0 MW	#2	1	Full	0:11	21	50
37	2.5 MW	#2	1	Full	0:24	20	47
38	1.0 MW	#2	1	Full	1:30	19	42

The effects of adequate mist delivery to the fire location and the need for oxygen depletion are well illustrated in Figure 12. The extinguishment times for the 1.0 MW fire ranged from twenty four seconds for adequate mist concentration to three minutes and thirty seconds for areas with little if any mist. The extinguishment times for the larger fires (5.0 MW) only increased by about twenty seconds for the same degree of obstruction.

8.3 Fuel Type Comparison

An extinguishment time comparison between heptane (-4°C (25°F) flashpoint) and F76 (60°C (140°F) flashpoint), the primary fuel used in Navy machinery spaces, is shown in Table 4 and

Figure 13. These fires were conducted under a two meter horizontal obstruction plate. As shown in Figure 13, the extinguishment times for the two fuels were similar for the larger fires, but varied dramatically as the fire size was reduced. The time required to extinguish the 1.0 MW F76 spray fire was a factor of three less than that observed for heptane (one minute for the F76 as compared to three minutes for heptane). The extinguishment time for the 0.5 MW spray fire produced using F76 was over an order of magnitude less than the extinguishment time for the 0.5 MW heptane spray fire (less than a thirty seconds for F76 as compared to almost five minutes for heptane). This suggests that the smaller diesel fuel spray fires may be unstable, making them easier to extinguish. Although not supported by these results, it is believed that the extinguishment times for the smaller (less than 1.0 MW) obstructed F76 fires will exponentially increase with decreased fire size. For a given fire size, the fires produced using F76 were extinguished faster than those produced with heptane. As a result, the capabilities observed during these tests can be viewed as conservative when predicting the performance of this system in typical Navy machinery space applications.

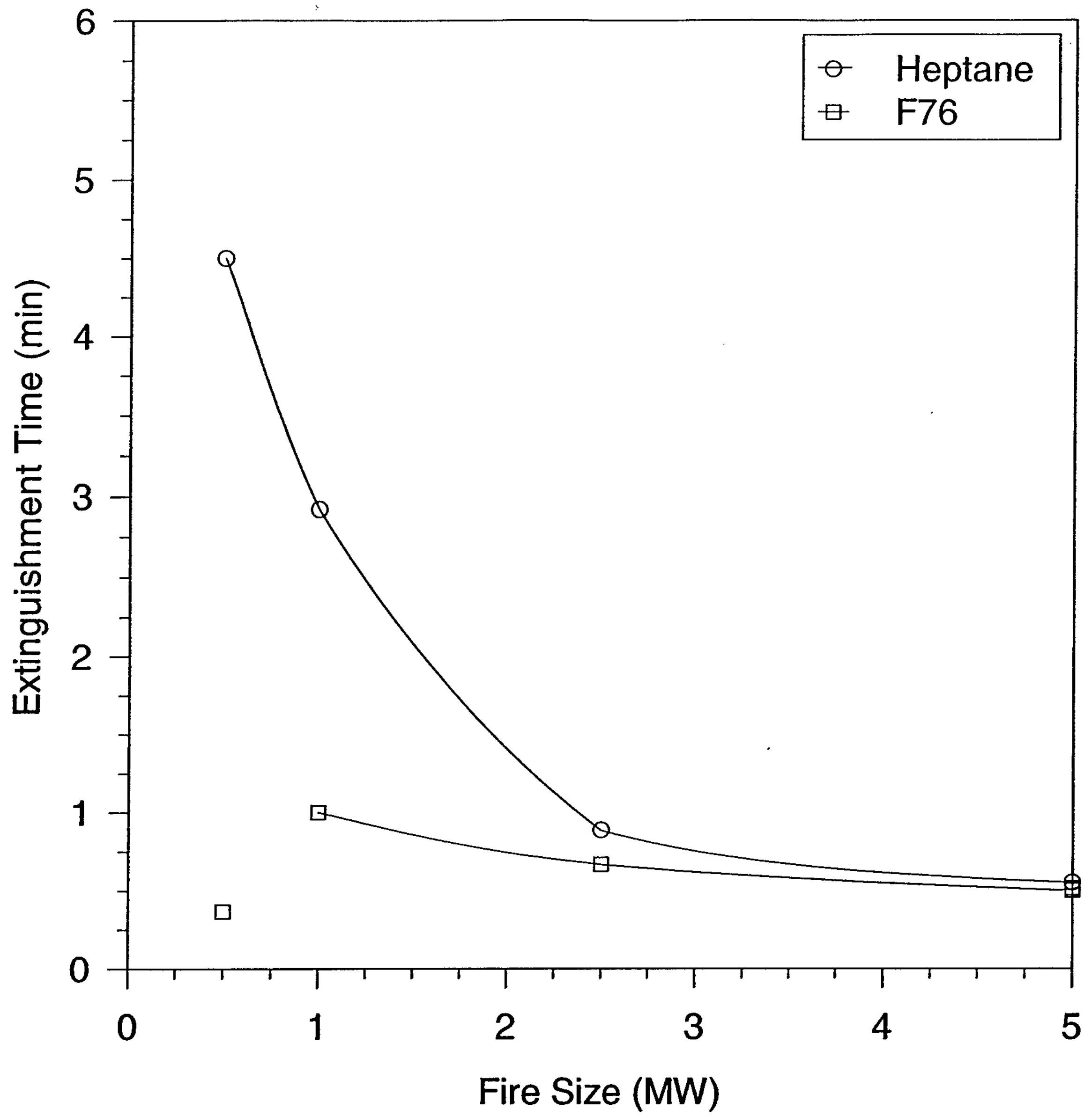
Table 4. Fuel Comparison

Test No.	Fuel	Fire Size (MW)	Fire Location	Mist System	Extinguishment Time* (min:sec)	Oxygen Concentration at Extinguishment ** (%) Dry	Steady-state Compartment Temperature*** (°C)
30	Heptane	5.0	#1	6	0:40	16	50
31	Heptane	5.0	#1	6	0:33	16	50
32	Heptane	2.5	#1	6	0:53	17	48
33	Heptane	1.0	#1	6	2:55	16	45
45	F76	5.0	#1	6	0:31	-	50
46	F76	5.0	#1	6	0:30	17	47
47	F76	2.5	#1	6	0:40	18	47
48	F76	1.0	#1	6	1:07	18	43
49	F76	1.0	#1	6	1:00	18	43
50	F76	0.5	#1	6	0:22	20	38
56	Heptane	0.5	#1	6	4:44	18	36

* Extinguishment times were measured from mist discharge.

** Oxygen concentrations shown in the table are the average of the four measurements recorded during the test.

*** The steady-state compartment temperature is defined as the uniform compartment temperature reached just prior to extinguishment.



Fire location #1
2.0 m (6.6 ft) horizontal obstruction

Fig. 13 – Fuel type comparison

8.4 Preburn Time Evaluation

The effect of preburn time on fire extinguishment was also evaluated during this test series. The tests were conducted using the 1.0 MW heptane spray fire under the two meter horizontal obstruction at Fire Location #1 with the preburn times varying from one to three minutes. A small fire was selected for this evaluation to minimize both the damage to the space and the amount of oxygen depletion prior to mist system activation. The results of the preburn analysis are shown in Figure 14. The data suggest that the fire burn time (the sum of the preburn time and the extinguishment time) is roughly constant for obstructed spray fires. This results from an increase in compartment temperature and a decrease in oxygen concentration resulting from the preburn. Based on these results, it is recommended that the water mist system be activated immediately upon fire detection. The activation of the mist system will control the compartment temperatures and minimize damage to the equipment in the space while the space is either being secured or manual intervention is being implemented.

8.5 Reduced Operating Pressure Tests

The ability of the water mist system to extinguish a 2.5 MW heptane spray fire located under a two meter horizontal obstruction at lower operating pressures 28 and 42 bar (400 and 600 psi) was also evaluated. These pressures represent two types of system failures. The expected system pressure, if one of the nozzles were missing is 28 bar (400 psi). This assumes a 0.375 dia. passage leading to the nozzle. The expected system pressure if one of the orifices cap assemblies in a nozzle was missing is 42 bar (600 psi). These expected pressures were determined by adjusting the k-Factor for the system based the additional flow resulting from the failure. This was done using an orifice flow calculation and the resulting opening area/diameter. The resulting lower system pressures affect the spray characteristics (drop size and velocity) of the system and reduces the amount of mist discharged by the system. The effect of reducing the system operating pressure on the fire extinguishing capabilities of the system is shown in Figure 15. The reduction in system pressure and flow rate resulted in significantly longer extinguishment times but did not constitute a total failure of the system.

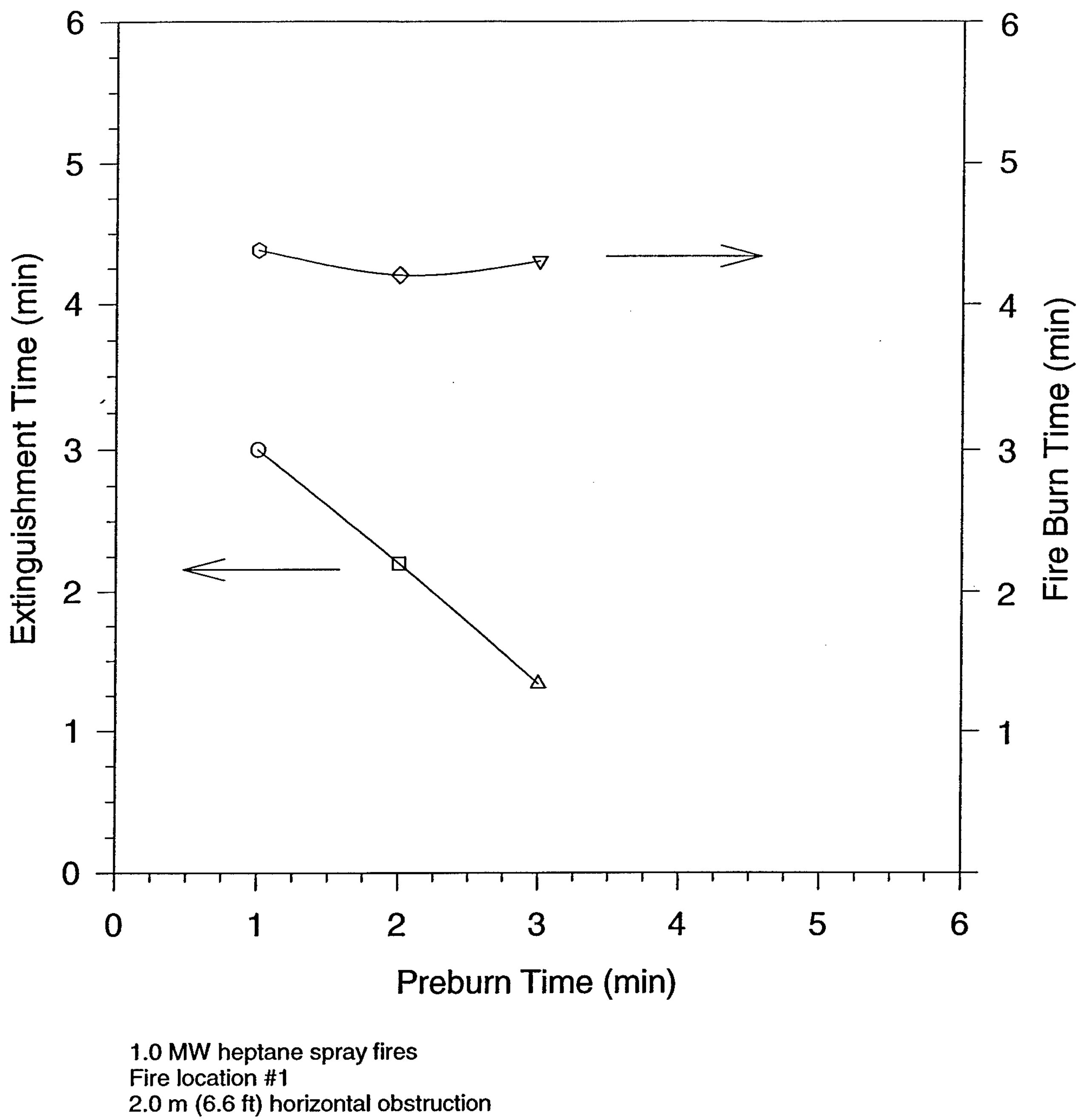
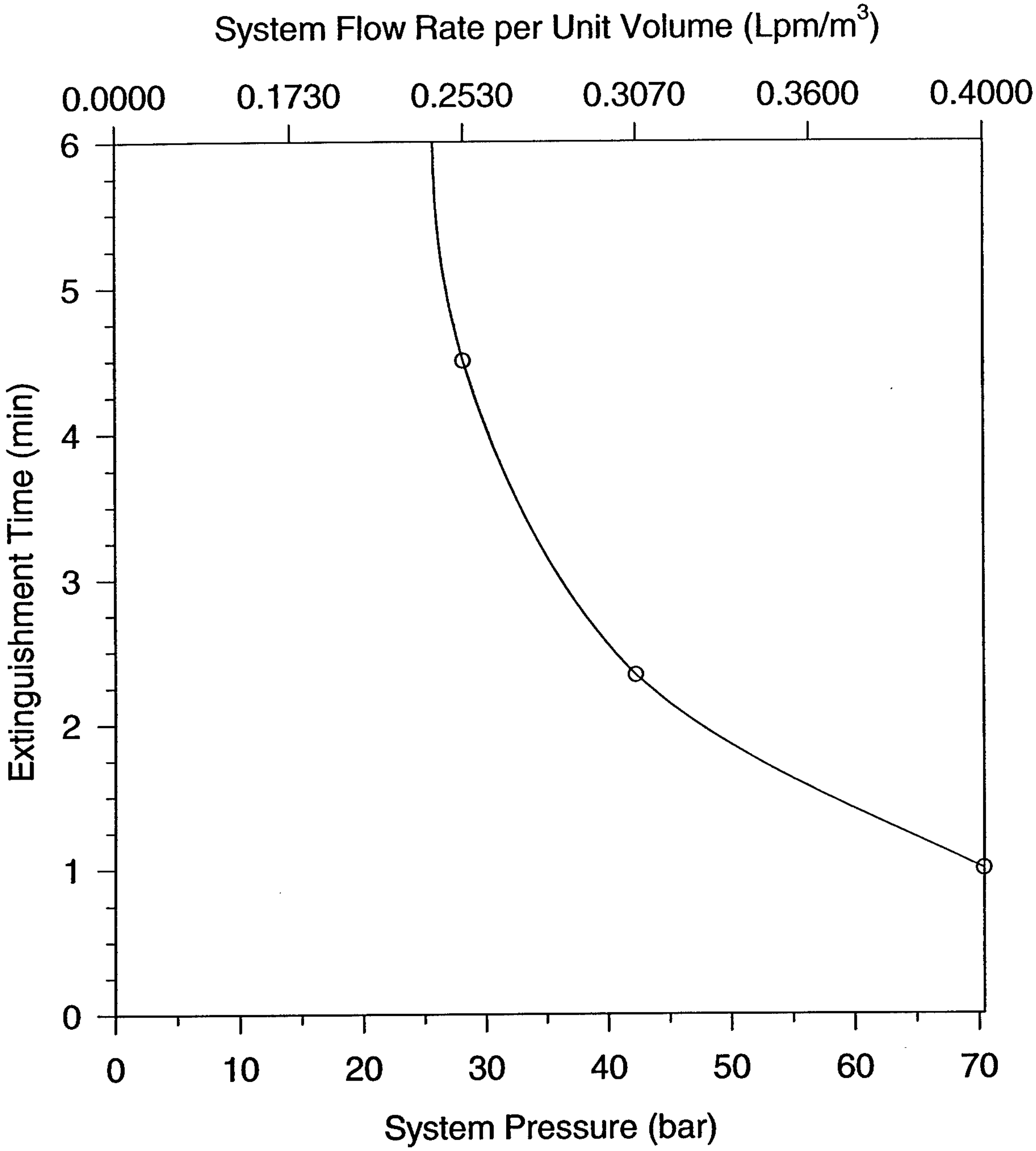


Fig. 14 – Preburn time analysis



2.5 MW heptane spray fires
Fire location #1
2.0 (6.6 ft) horizontal obstruction

Fig. 15 – Effects of reduced system pressure

8.6 Open Compartment Tests

An analysis was also conducted to determine the variation in capabilities of the mist system in an open compartment (doors to weather remained open). During this test, three doors open to either the weather or to other parts of the ship remained open. These doors include: one in the vestibule on the third deck, one on the fourth deck forward in the space and one on the fifth deck leading to the escape hatch/trunk. The combined opening produced a ventilation factor ($A\sqrt{H}$) of 6.2 $m^{5/2}$. The net effect of allowing the doors to remain open during the fire was a slight increase in the extinguishment time for the smaller fires but had little if any effect on the extinguishment times for the larger fires. This is shown in Figure 16. The ability of the system to extinguish fires in open spaces adds a robustness to the system not provided by the gaseous halon alternatives.

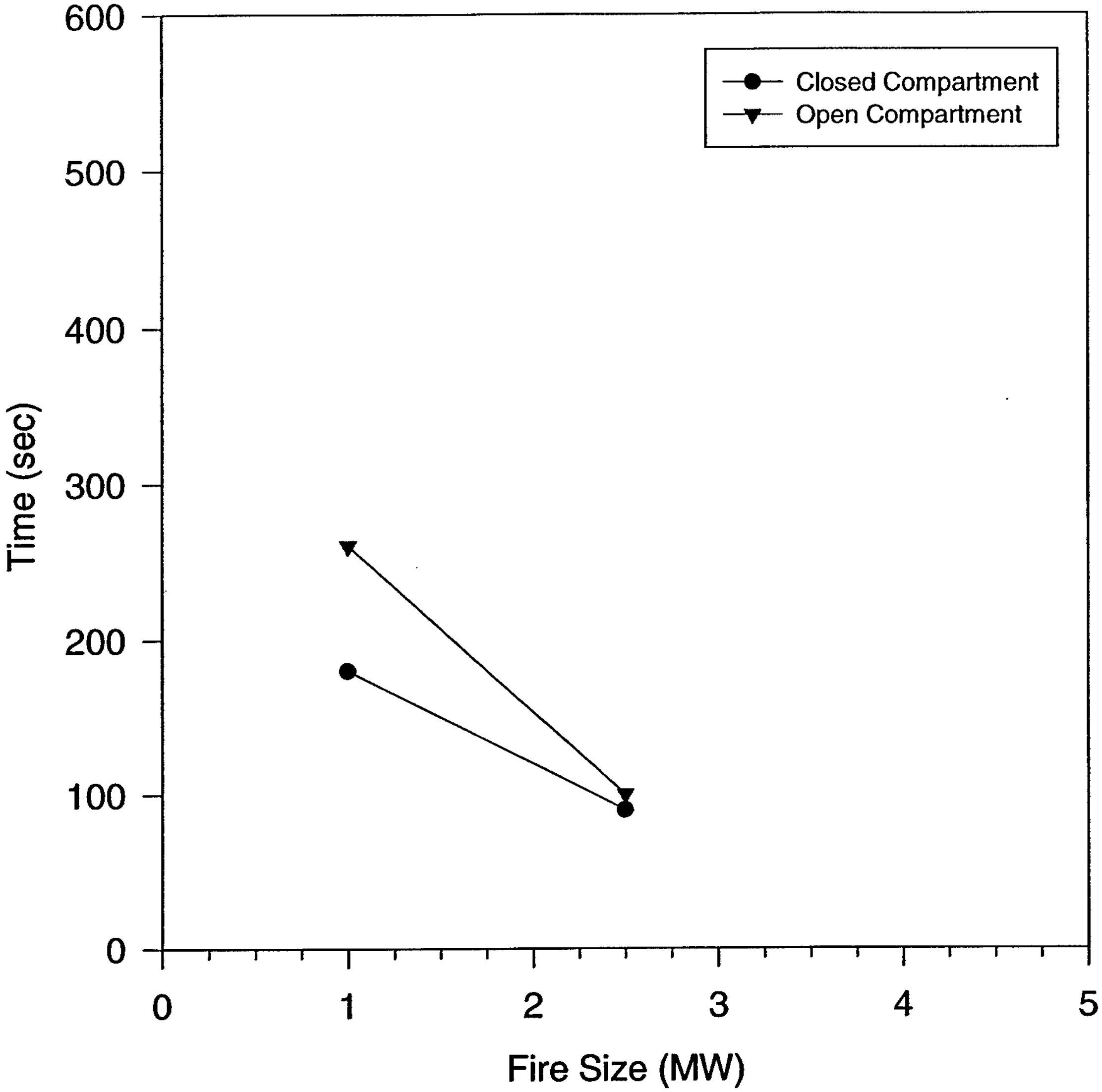
8.7 Scaling Evaluation

With the capabilities and limitations of the system identified, a series of tests was conducted to provide insight on how the results from this test series would scale to the larger machinery spaces on the LPD-17. The machinery spaces on the LPD-17 are over twice the size (volume) of the test compartment on the ex-SHADWELL. The compartment volumes for these spaces are shown in Table 5.

Table 5. Machinery Space Volumes

Compartment	Volume m^3 (ft^2)
SHADWELL FR29 - FR22	450 (16000)
SHADWELL FR36 - FR22	900 (31400)
LPD-17 AMR 1-3	1850 (66300)
LPD-17 MMR 1 & 2	2150 (75800)

To identify the effects that the compartment volume has on the extinguishment times and capabilities of the system, a series of tests was conducted in the forward half of the space with the doors at frame 29 secured. The approach was to determine the effect that reducing the



2.5 MW heptane spray fires
Fire location #1
2.0 m (6.6 ft) horizonal obstruction

Fig. 16 – Ventilation comparison

compartment volume (reduced by 50 percent) had on the results of these tests and use these effects/trends to extrapolate the data to larger compartments.

The results of the previous tests suggest that increasing the compartment volume has varying effects on the extinguishment process. If the fires are located in areas where adequate mist reaches the fire (unobstructed fires), increasing the compartment volume has a minimal effect on the extinguishment time. If, however, a reduction in the oxygen concentration is required to extinguish the fire (i.e., obstructed locations), an increase in compartment volume results in longer extinguishment times. For this reason, obstructed fires (2.0 m (6.6 ft) horizontal obstructions) were selected for this scaling evaluation.

The results of scaling tests are summarized in Table 6. The extinguishment times recorded for these heptane spray fires are plotted as a function of fire size in Figure 17. The effect of reducing the volume of the compartment by 50 percent decreased the extinguishment times by 30-50 percent (30 percent for the larger fires (>1.0 MW) and up to 50 percent for the smaller fires (<1.0 MW)).

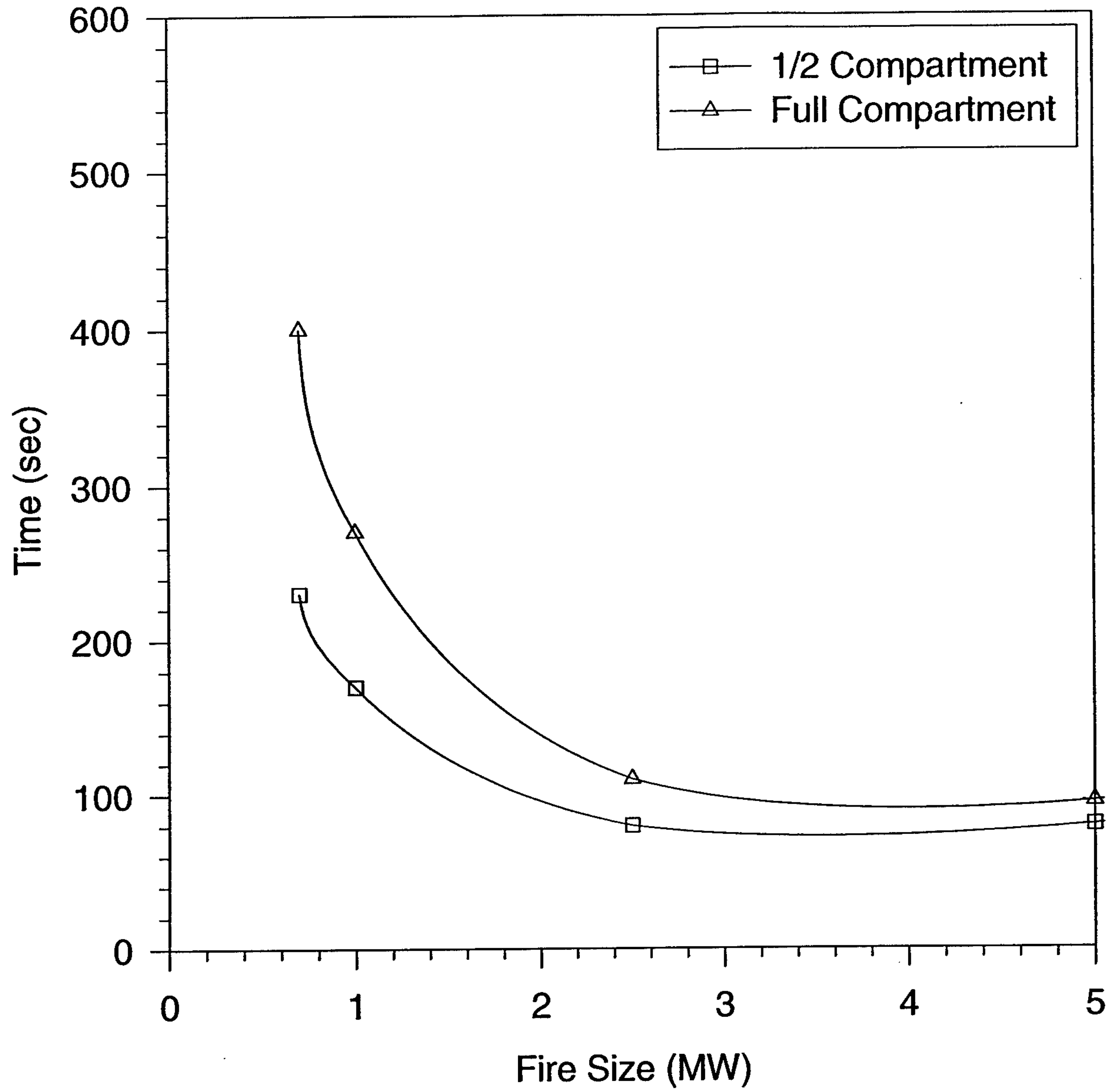
Table 6. Compartment Size Comparison

Test #	Fire Size	Fire Location	Mist System	Compartment Configuration	Extinguishment Time * (min:sec)	Oxygen Concentration at Extinguishment ** (%)	Steady-state Compartment Temperature *** (°C)
30	5.0 MW	#1	6	Full	0:40	16	50
31	5.0 MW	#1	6	Full	0:33	16	50
32	2.5 MW	#1	6	Full	0:53	18	48
33	1.0 MW	#1	6	Full	2:55	17	45
56	0.5 MW	#1	6	Full	4:44	18	36
51	5.0 MW	#1	6	Half	0:18	17	50
52	2.5 MW	#1	6	Half	0:43	16	45
53	1.0 MW	#1	6	Half	2:20	17	48
54	0.5 MW	#1	6	Half	3:02	17	38
55	0.5 MW	#1	6	Half	2:40	18	40

* Extinguishment times were measured from mist discharge.

** Oxygen concentrations shown in the table are the average of the four measurements recorded during the test.

*** The steady-state compartment temperature is defined as the uniform compartment temperature reached just prior to extinguishment.



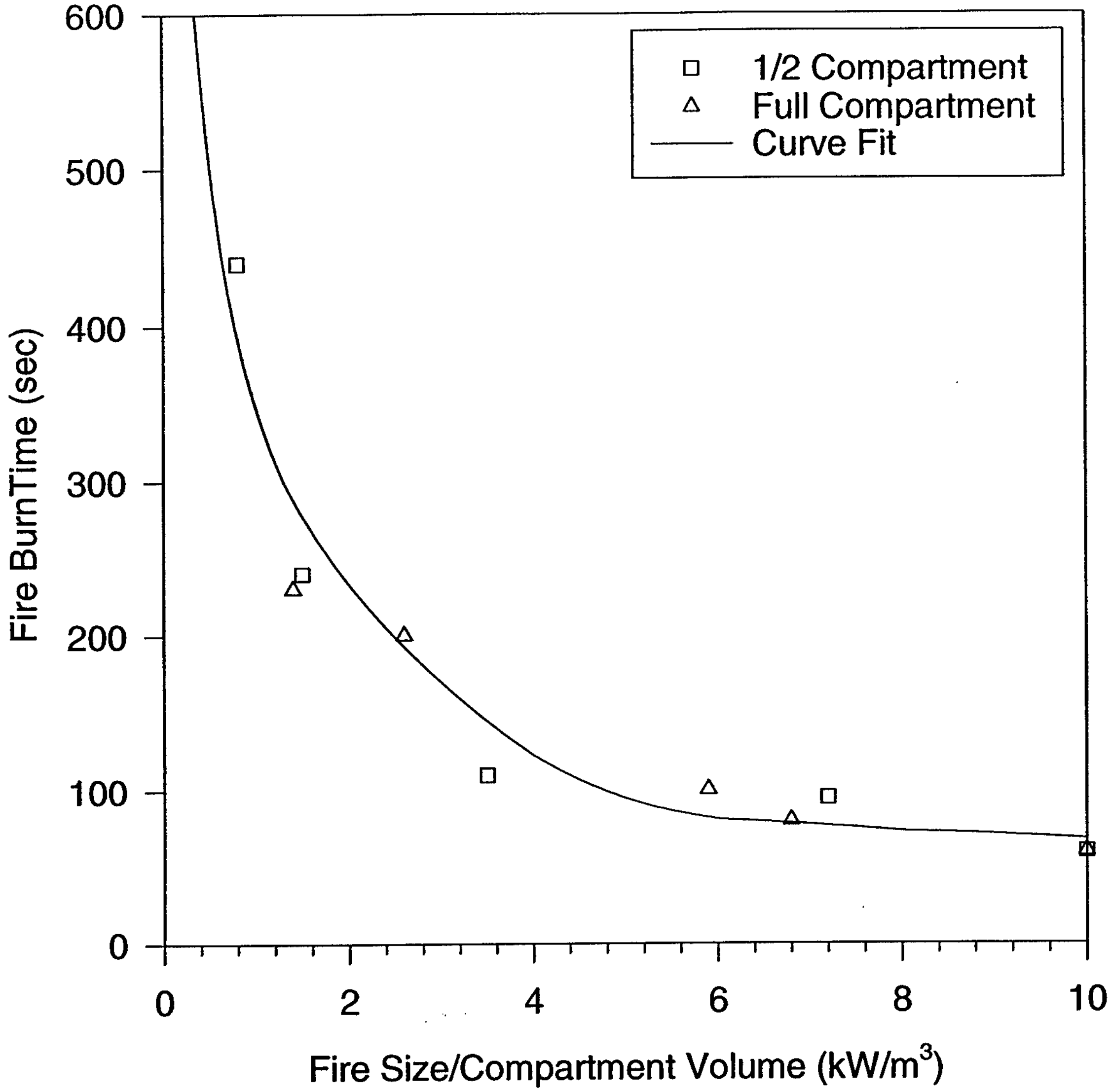
Heptane spray fires
Fire location #1
2.0 m (6.6 ft) horizontal obstruction

Fig. 17 – Fire compartment volume comparison

To scale these results to the larger machinery spaces on the LPD-17, the effects of oxygen depletion had to be addressed. In compartments with limited ventilation, oxygen depletion effects scale directly with compartment volume. To demonstrate this concept, the results (extinguishment times) of these tests were analyzed based on the ratio of fire size to compartment volume. To account for the reduction in oxygen that occurred in the space during the preburn, the fire burn time (preburn time plus extinguishment time) was used in this analysis. The fire burn times were plotted versus the fire size to compartment volume ratio in Figure 18. A curve fit was used to approximate the relation identified by the data. The relation determined by the curve fit was then used to predict the fire burn times and the expected extinguishment times (assuming a one minute preburn) for a range of fire sizes for the main (2150 m^3 (75800 ft^3)) and auxiliary (1850 m^3 (66300 ft^3)) machinery spaces on the LPD-17 (Figure 19).

The extinguishment times shown in Figure 19, were developed using the results of the tests conducted with heptane and should be significantly less for typical Navy fuels (i.e., F76). The results of this analysis suggest fires occurring in the main or auxiliary machinery spaces on the LPD-17 with heat release rates greater than 2.0 MW would be extinguished within three minutes of mist system activation, if the ventilation (natural and forced) to the space was secured prior to or during mist discharge. Increases in ventilation would tend to lengthen these extinguishment times. Smaller fires would also be extinguished but would require additional time. Historically, the fires that have occurred in machinery spaces are extremely large (>>2.0 MW) and would be extinguished in less than one minute.

In an attempt to quantify the hazard associated with the 2.0 MW fire discussed previously, a perspective on fire size has been developed for F76 pool fires and is shown in Figure 20 [6]. The lines on this Figure represent the pool fire diameters and flame heights of various size fires. As shown in this Figure, a 2.0 MW fire is approximately one meter in diameter and can easily be approached and extinguished using a portable PKP extinguisher. The smallest PKP extinguisher used by the Navy (18 lb (8 kg) capacity) is rated for pool fires with areas on the order of 6 m^2 (60 BC) [7]. This corresponds to a fire with a heat release rate greater than 5.0 MW. To further



Heptane spray fires
Fire location #1
2.0 m (6.6 ft) horizontal obstruction

Fig. 18 – Fire burn time analysis

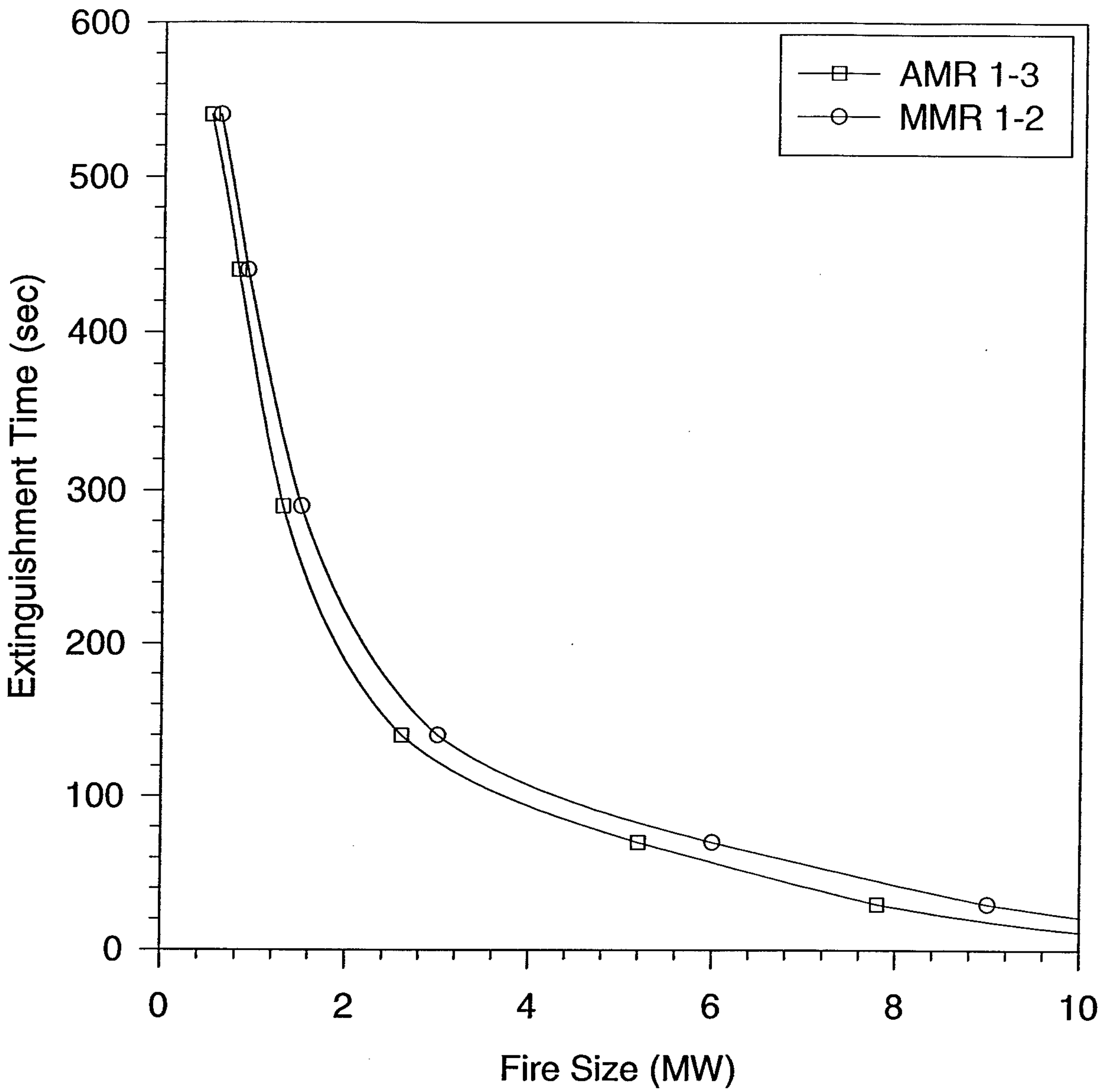


Fig. 19 – Predicted extinguishment times for LPD-17

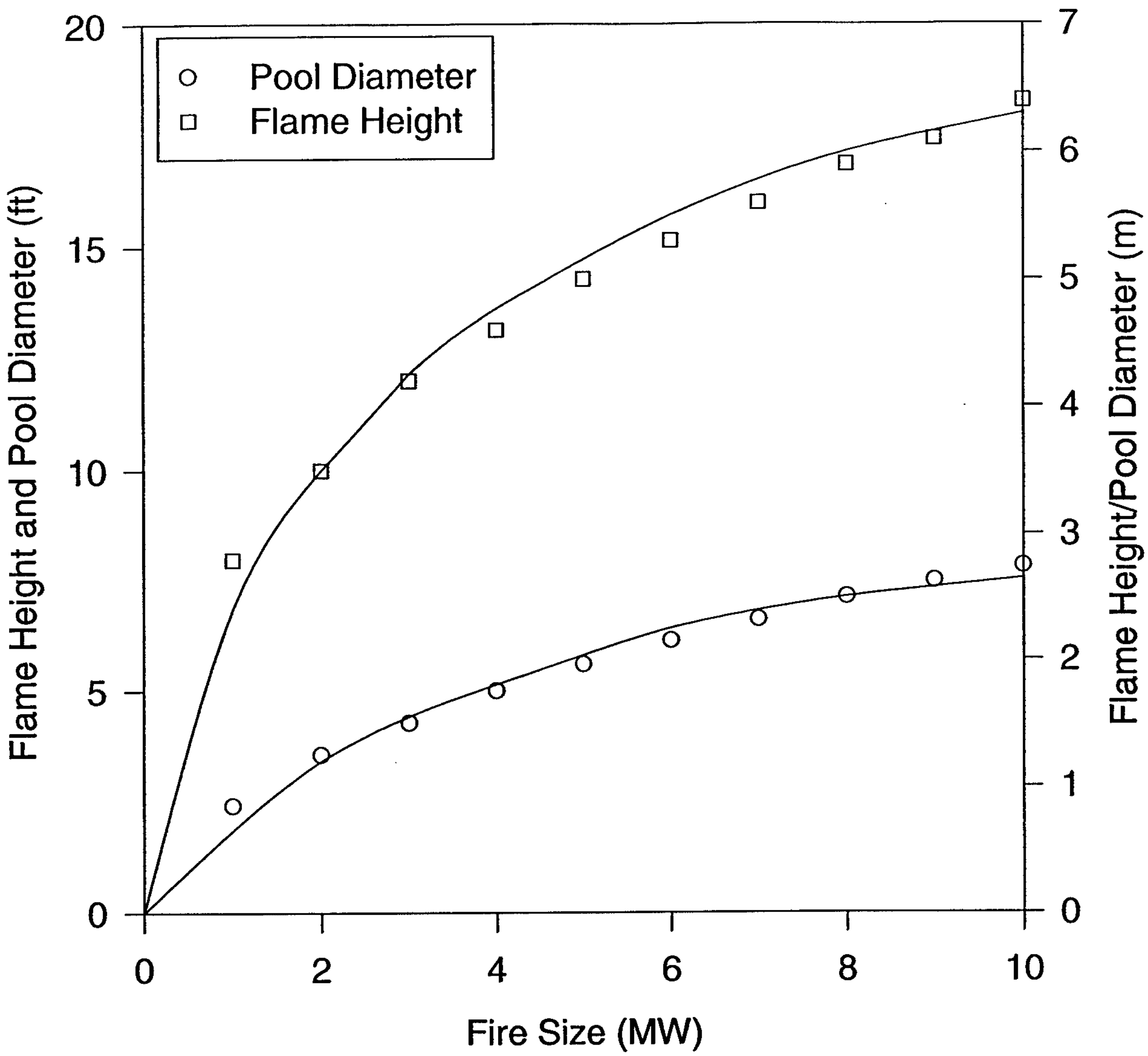


Fig. 20 – Fire size perspective (F76 pool fires)

support this notion, two additional tests were conducted to demonstrate this capability and identify any adverse effects that the mist has on the performance of the PKP extinguisher. During these tests, a firefighter was able to approach and instantly extinguish both a 1.0 MW and 2.0 MW heptane spray fires.

9.0 SUMMARY AND CONCLUSIONS

The water mist nozzle developed in the early stages of the Navy's investigation into the use of water mist in machinery space applications was redesigned and reevaluated during this test program. The redesigned nozzle consisted of a Spraying Systems Model 7N nozzle body containing seven Model 1/4LN orifice cap assemblies. The nozzle was evaluated in a system design consisting of two levels of nozzles installed with a nominal 3.0 m (10 ft) nozzle spacing. The upper level nozzles consisted of six 1/4LN2 orifice caps (CP 1206 and CP 1207-2) with an orifice insert from a 1/4LN26 (CP 3781-26) installed around the perimeter of the nozzle and a standard 1/4LN12 orifice cap assembly installed in the center (CP 1206, CP 1207 and CP 3781-12). For the lower level nozzles, the six orifice cap assemblies installed around the perimeter were 1/4LN1.5 orifice caps (CP 1206 and CP 1207-1.5) with an orifice insert from a 1/4LN26 (CP 3781-26). The center orifice cap assembly was a standard 1/4LN2 (CP 1206, CP 1207-2 and CP 3781-2).

With the space secured (doors closed and the ventilation system secured), the water mist system was capable of extinguishing all the unobstructed fires in less than one minute, and all of the obstructed fires 1.0 MW or larger in less than three minutes and thirty seconds. The results of these tests were then scaled to the larger machinery spaces on the LPD-17. The scaling analysis suggests that the unobstructed fires would still be extinguished in less than one minute, and all of the obstructed fires 2.0 MW or larger would be extinguished in less than three minutes and thirty seconds. These extinguishment times were based on fires produced using heptane as the fuel and should be significantly less for typical Navy fuels (i.e., F76). It was also shown that fires requiring a longer time to extinguish can be easily approached and extinguished using a standard Navy portable extinguisher. This prototype system (nozzles and system design) has been

validated for use in the machinery spaces on the LPD-17. A detailed system description is found in Appendix B.

10.0 REFERENCES

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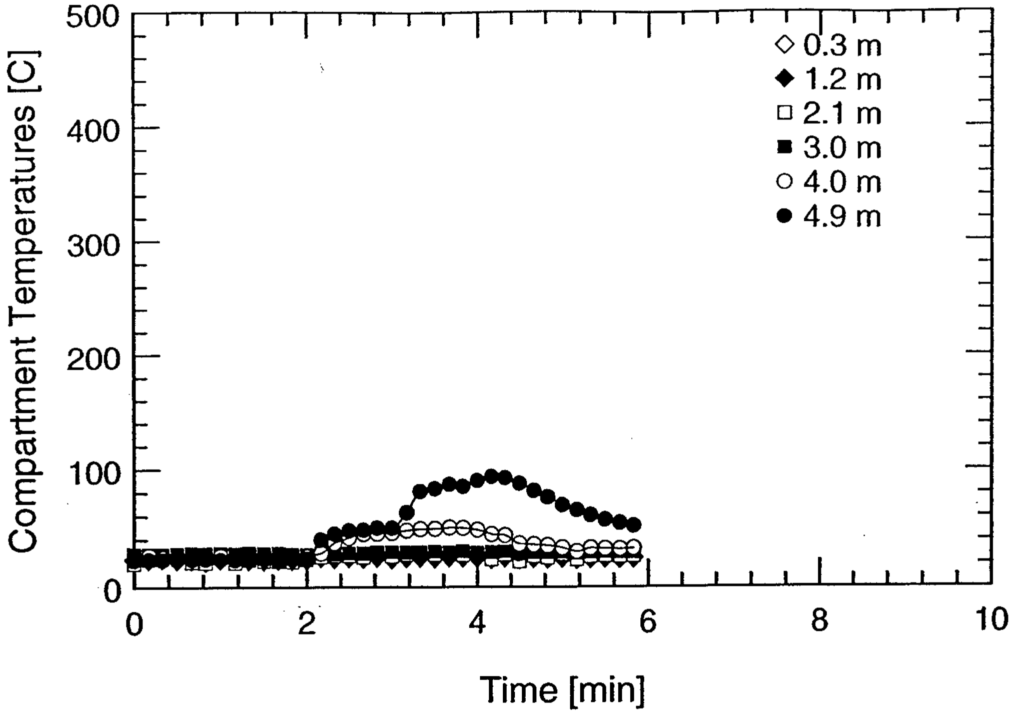
Appendix A

Test Data

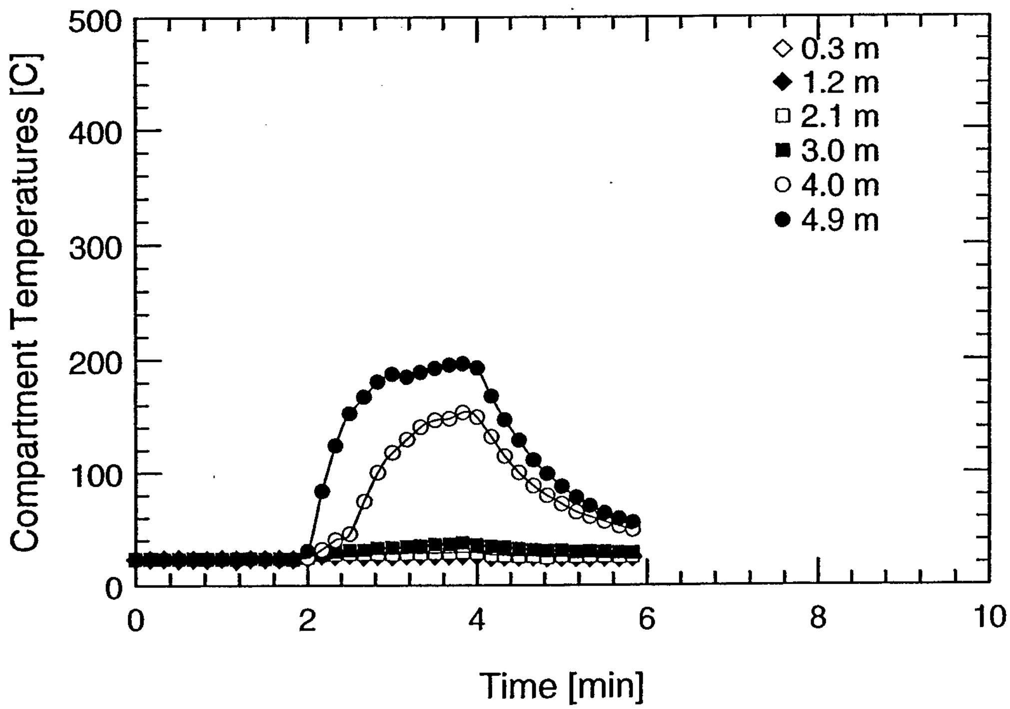
Table of Contents

Test #	System	Fire Size (MW)	Fire Location	Compartment	Page #
1	Freeburn	1.0 Heptane	#1	Full	A-4
2	1	5.0 Heptane	#1	Full	A-10
3	1	5.0 Heptane	#1	1/2	A-16
4	1	2.5 Heptane	#1	Full	A-22
5	1	2.5 Heptane	#1	1/2	A-28
6	1	1.0 Heptane	#1	Full	A-34
7	1	1.0 Heptane	#1	1/2	A-40
8	2	5.0 Heptane	#1	Full	A-46
9	2	5.0 Heptane	#1	Full	A-52
10	2	5.0 Heptane	#1	1/2	A-58
11	2	2.5 Heptane	#1	Full	A-64
12	2	2.5 Heptane	#1	1/2	A-70
13	2	1.0 Heptane	#1	Full	A-76
14	2	1.0 Heptane	#1	1/2	A-82
15	3	1.0 Heptane	#1	Full	A-88
16	3	2.5 Heptane	#1	Full	A-94
17	3	5.0 Heptane	#1	Full	A-100
18	3	50 Heptane	#1	1/2	A-106
19	3	2.5 Heptane	#1	1/2	A-112
20	3	1.0 Heptane	#1	1/2	A-118
21	4	1.0 Heptane	#1	Full	A-124
22	4	2.5 Heptane	#1	Full	A-130
23	4	5.0 Heptane	#1	Full	A-136
24	5	5.0 Heptane	#1	Full	A-142
25	5	5.0 Heptane	#1	1/2	A-148
26	5	2.5 Heptane	#1	Full	A-154
27	5	2.5 Heptane	#1	1/2	A-160
28	5	1.0 Heptane	#1	Full	A-166
29	5	1.0 Heptane	#1	1/2	A-172
30	6	5.0 Heptane	#1	Full	A-178
31	6	5.0 Heptane	#1	Full	A-184
32	6	2.5 Heptane	#1	Full	A-190

Test #	System	Fire Size (MW)	Fire Location	Compartment	Page #
33	6	1.0 Heptane	#1	Full	A-196
34	6	1.0 Heptane	#3	Full	A-202
35	6	1.0 Heptane	#3	Full	A-208
36	6	5.0 Heptane	#2	Full	A-214
37	6	2.5 Heptane	#2	Full	A-220
38	6	1.0 Heptane	#2	Full	A-226
39	6	1.0 Heptane 2:00 preburn	#1	Full	A-232
40	6	1.0 Heptane 3:00 preburn	#1	Full	A-238
41	6	2.5 Heptane	#1	Full	A-244
42	6	2.5 Heptane	#1	Full	A-250
43	6	2.5 Heptane	#1	Full	A-256
44	6	2.5 Heptane	#1	Full	A-262
45	6	5.0 F76	#1	Full	A-268
46	6	5.0 Heptane	#1	Full	A-274
47	6	2.5 Heptane	#1	Full	A-280
48	6	1.0 Heptane	#1	Full	A-286
49	6	1.0 Heptane	#1	Full	A-292
50	6	0.5 Heptane	#1	Full	A-298
51	6	5.0 Heptane	#1	1/2	A-304
52	6	2.5 Heptane	#1	1/2	A-310
53	6	1.0 Heptane	#1	1/2	A-316
54	6	0.5 Heptane	#1	1/2	A-322
55	6	0.5 Heptane	#1	1/2	A-328
56	6	0.5 Heptane	#1	Full	A-334
57	No	1.0 Heptane PKP	#1	Full	A-340
58	6	1.0 Heptane PKP	#1	Full	A-346
59	6	5.0 Heptane	#1	1/2	A-352
60	6	5.0 Heptane	#1	1/2	A-358
61	6	1.0 Heptane	#1	1/2	A-364
62	6	2.0 Heptane PKP	#1	Full	A-370
63	6	1.0 F76	#1	Full	A-376
64	6	5.0 F76	#1	Full	A-382

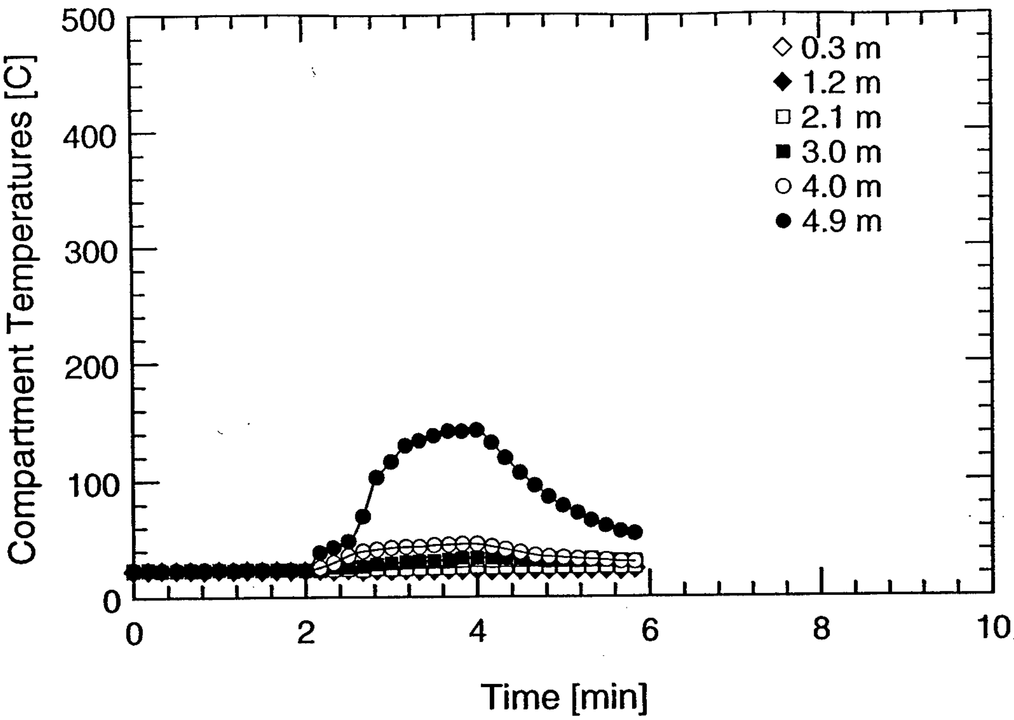


5-22-1

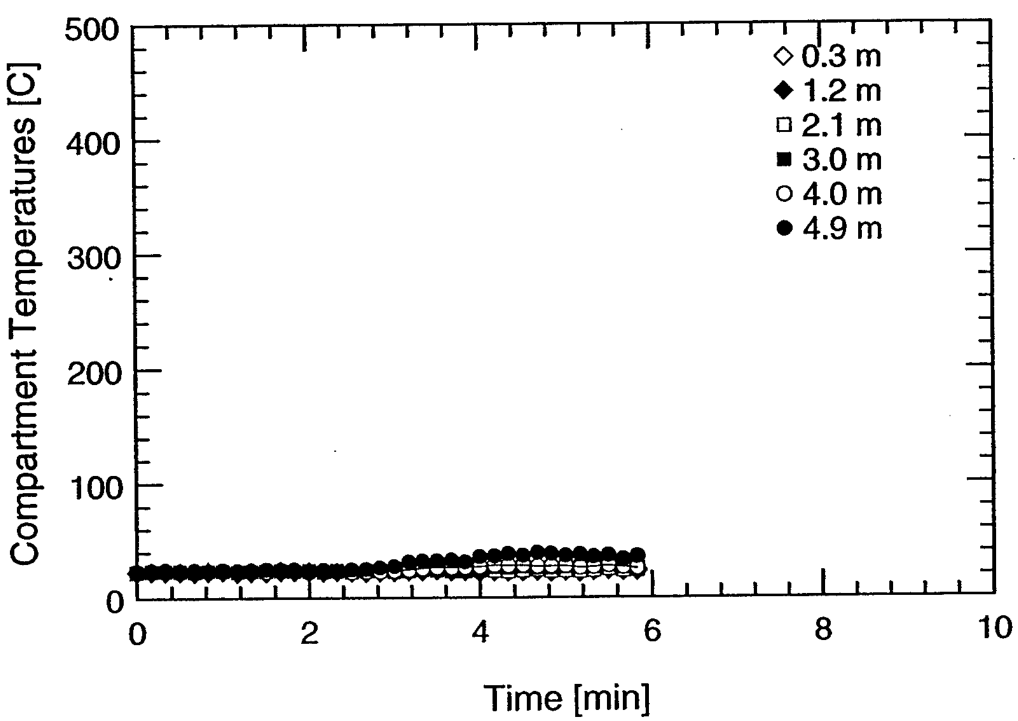


5-27-1

Test #1

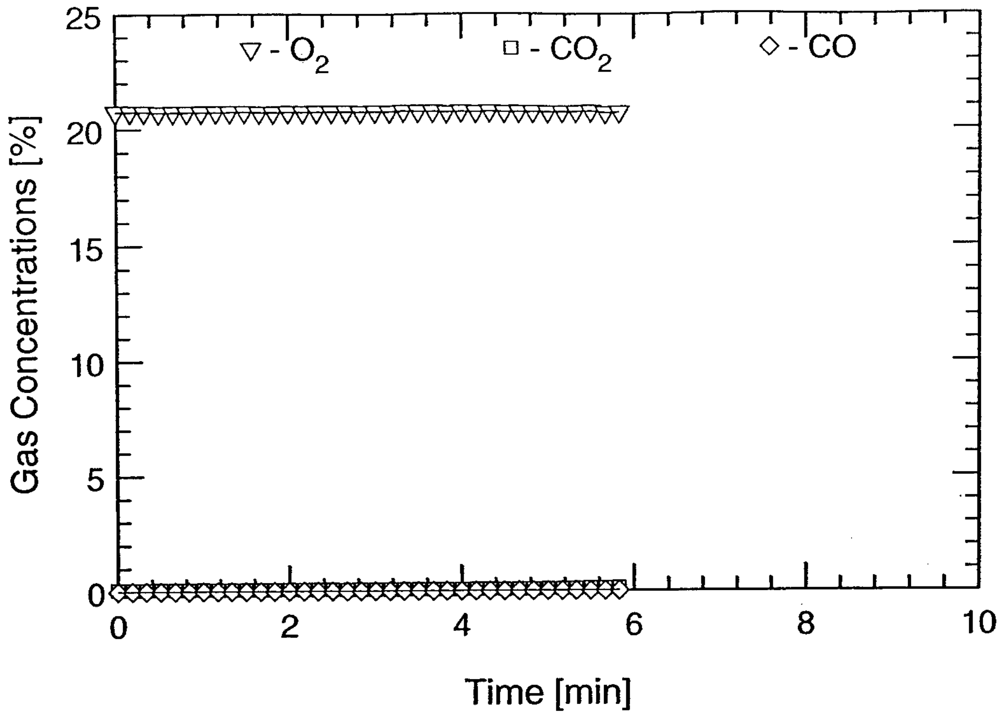


5-27-2

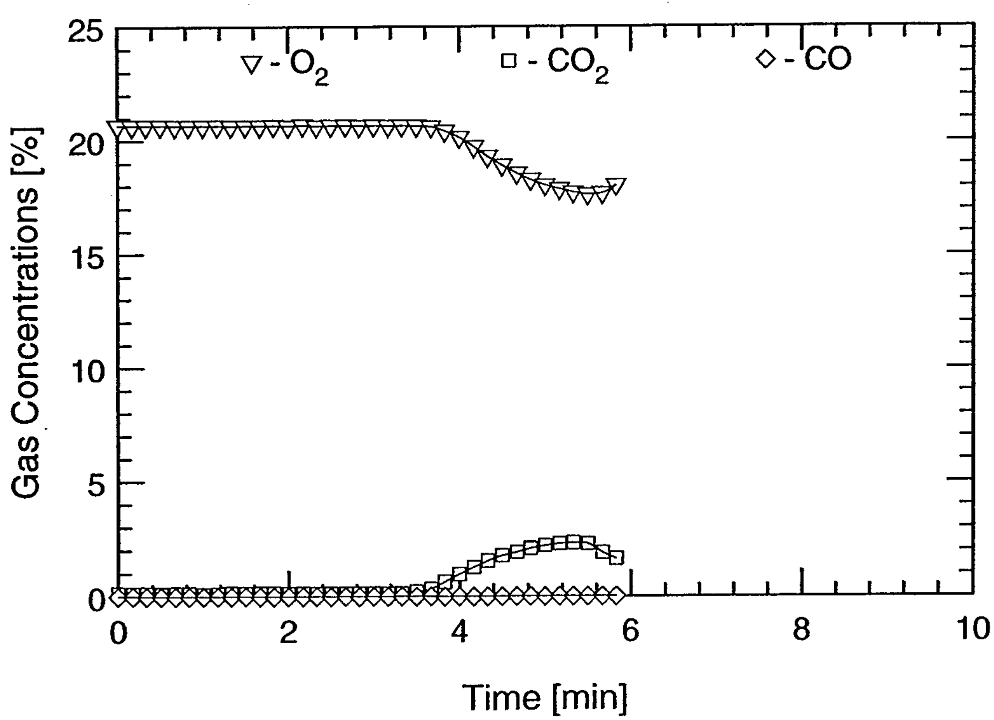


5-35-1

Test #1

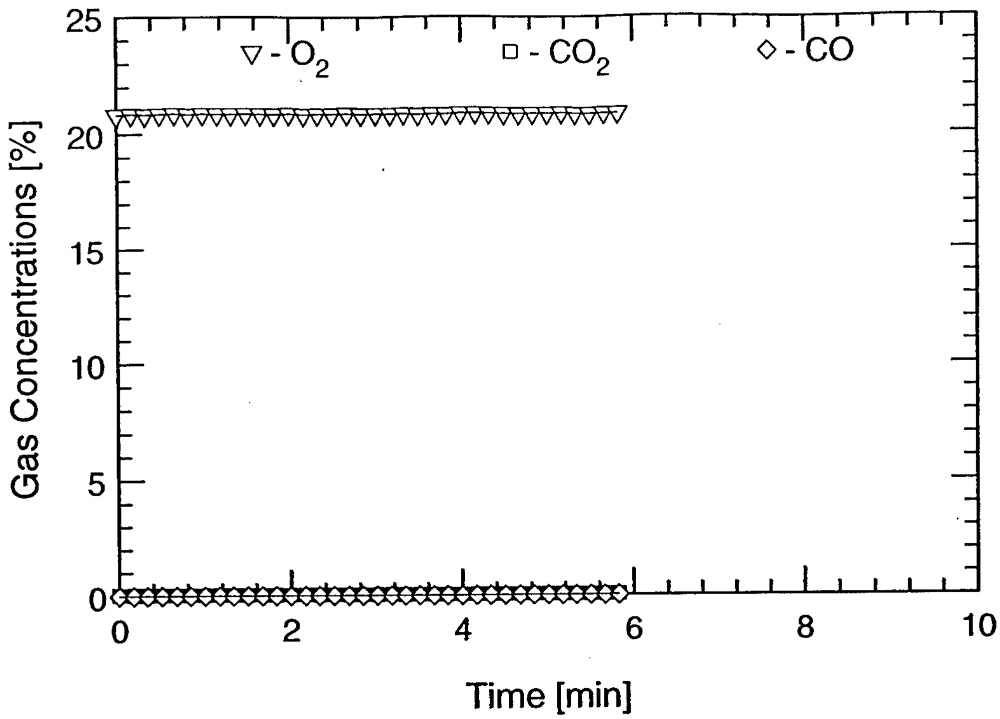


FR 22 - 0.5 m

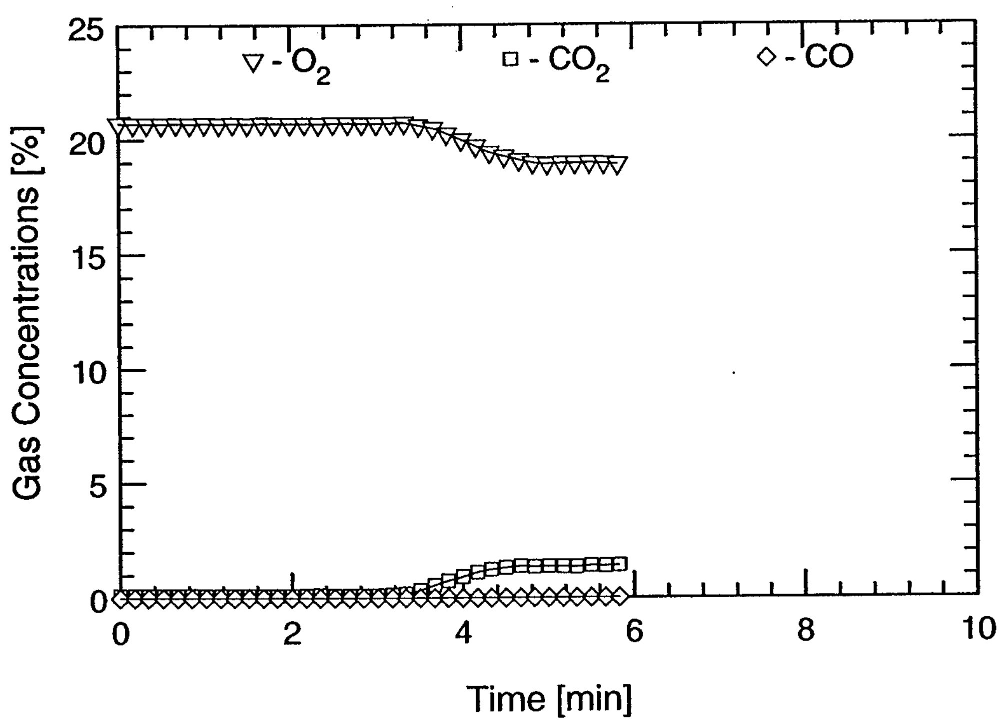


FR 22 - 4.5 m

Test #1

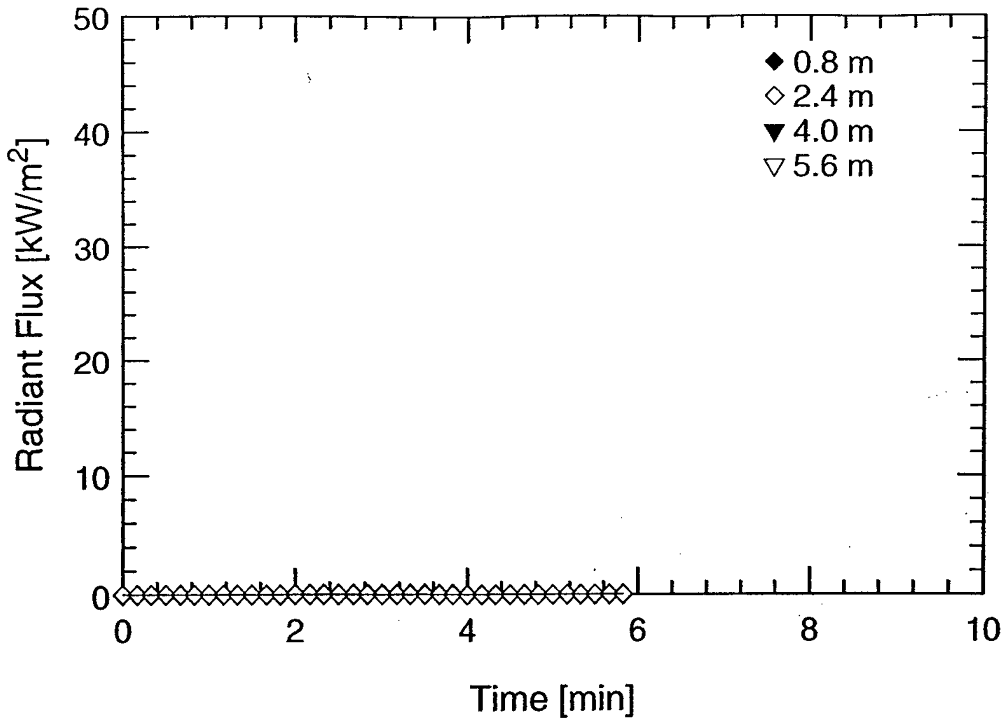


FR 36 - 0.5 m

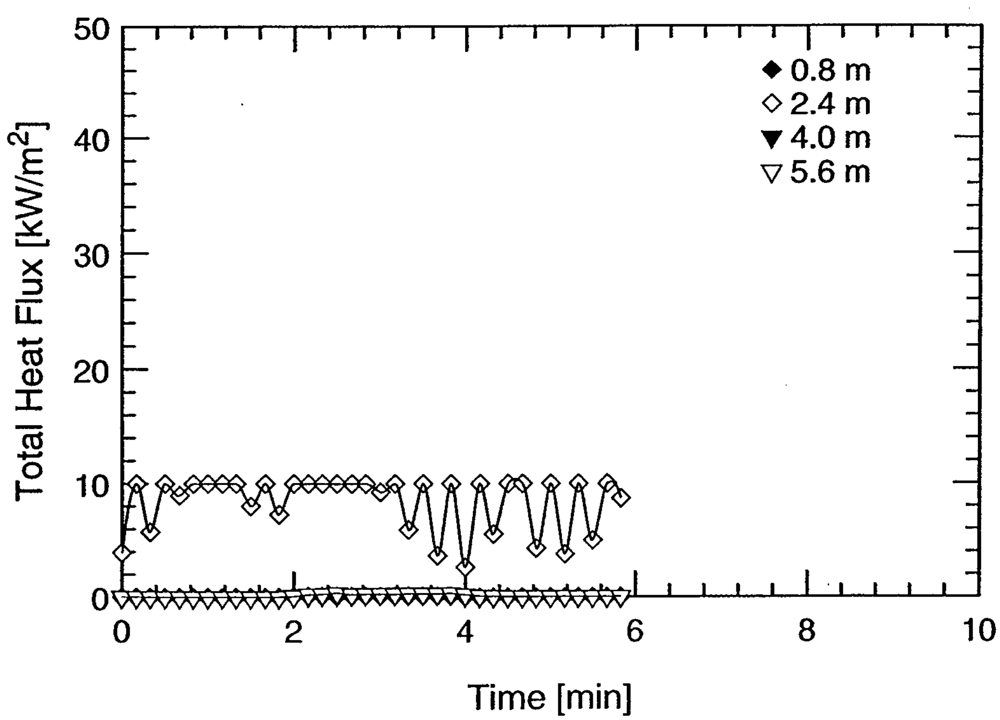


FR 36 - 4.5 m

Test #1

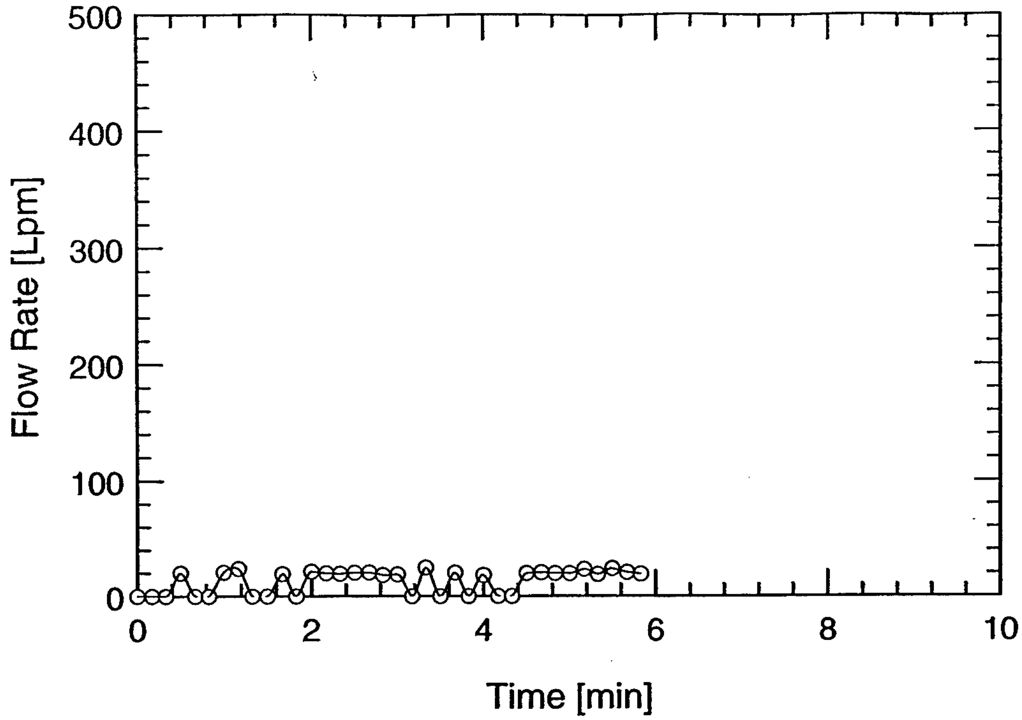


FR 22

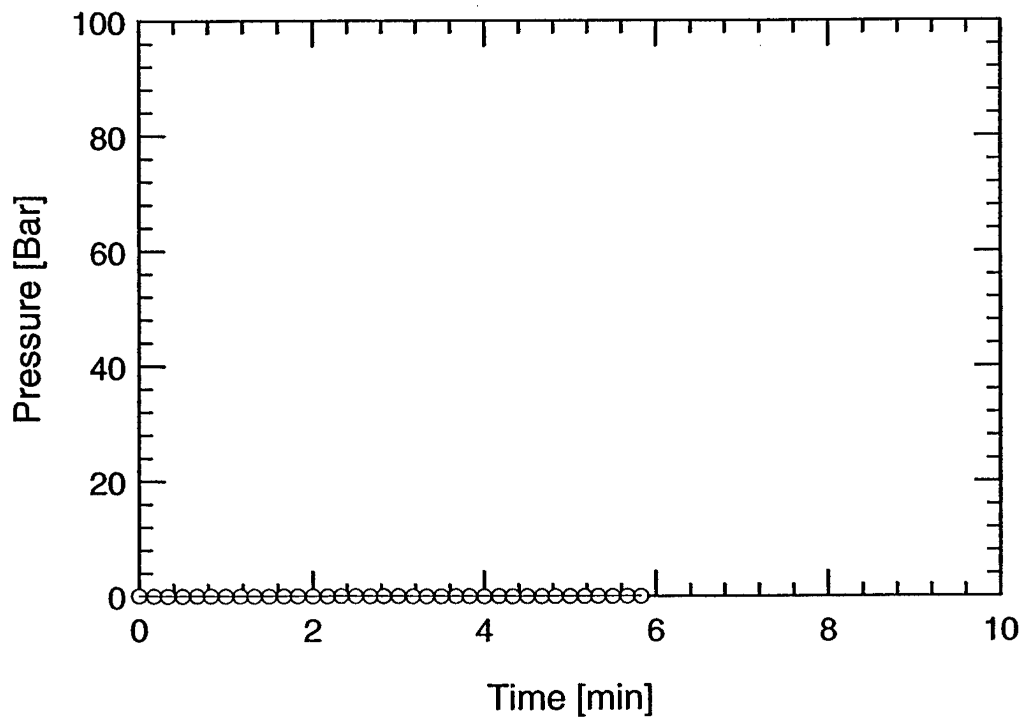


FR 22

Test #1

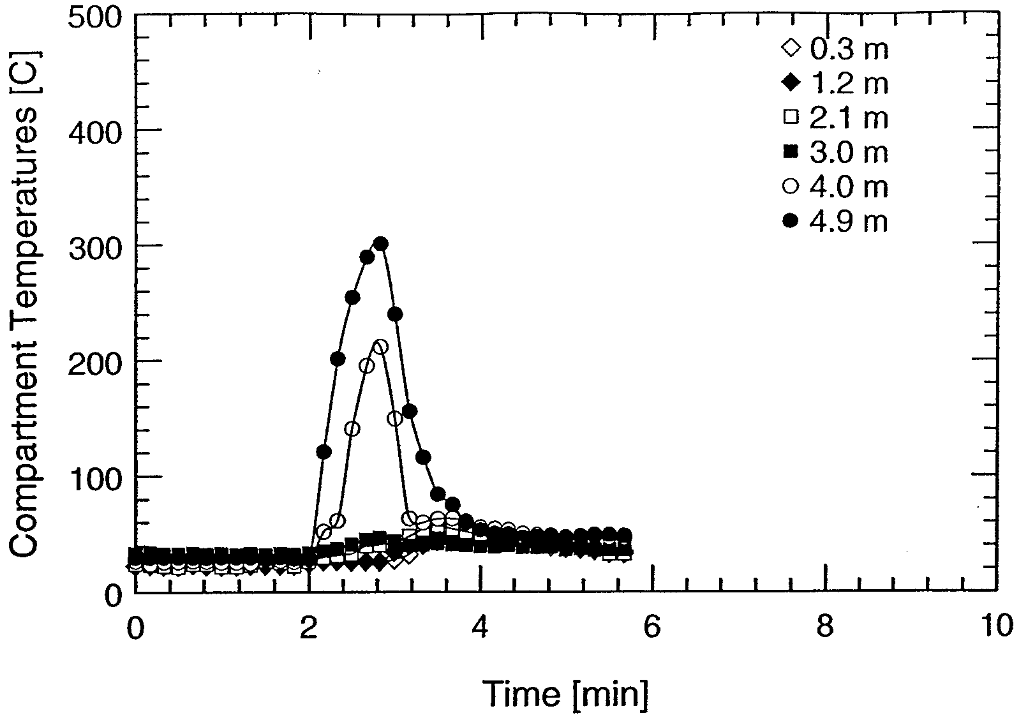


Water Mist System Flow Rate

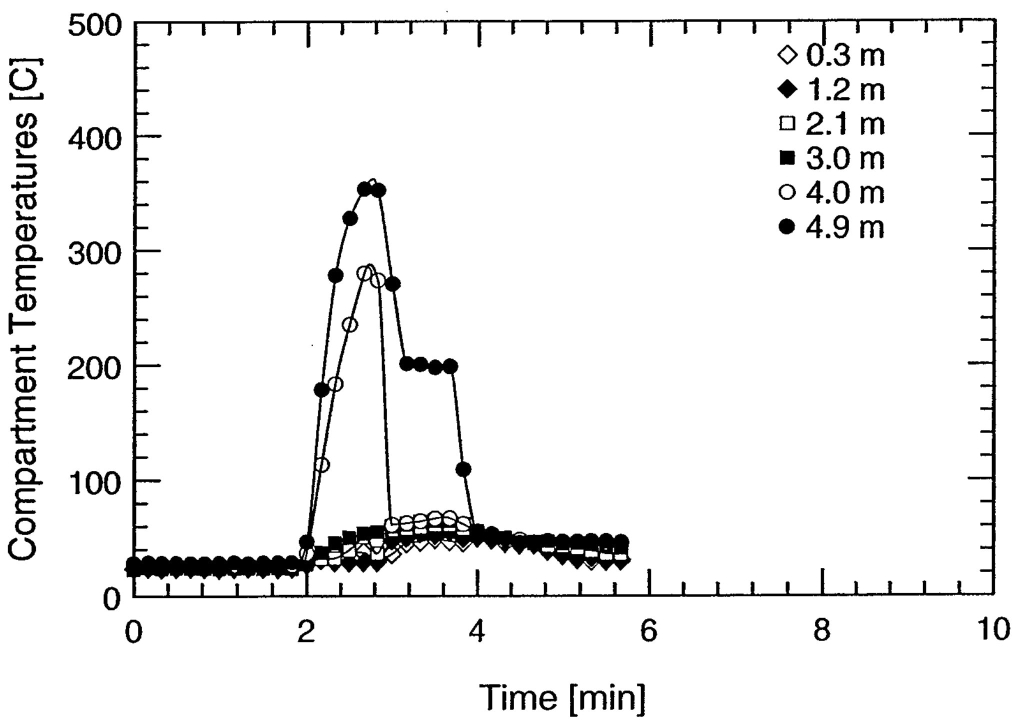


Water Mist System Pressure

Test #1

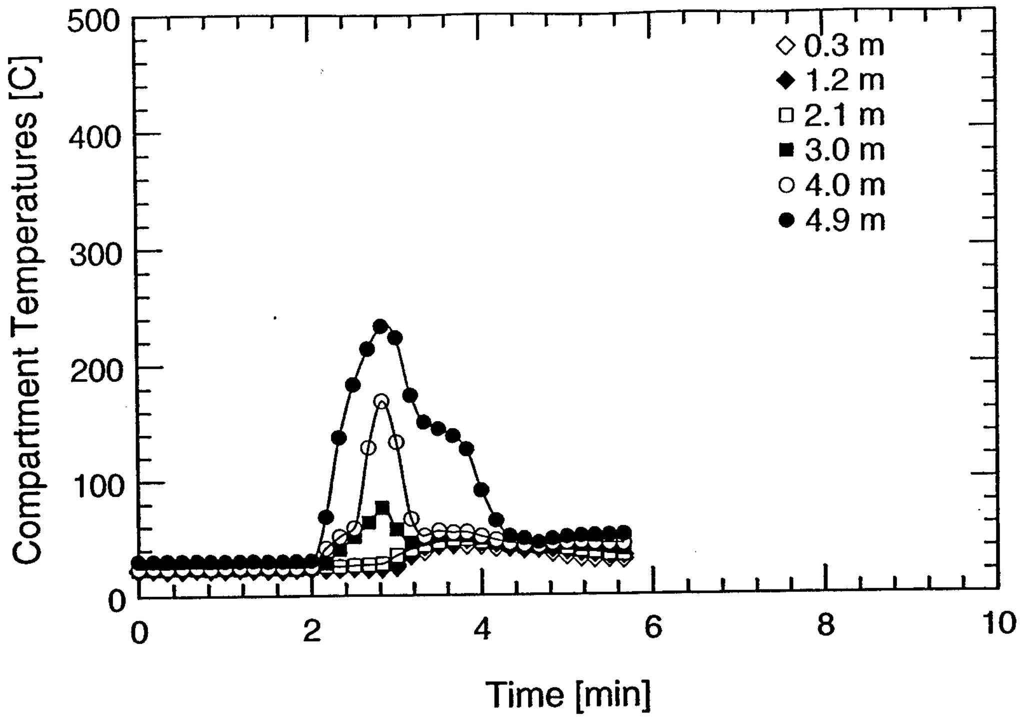


5-22-1

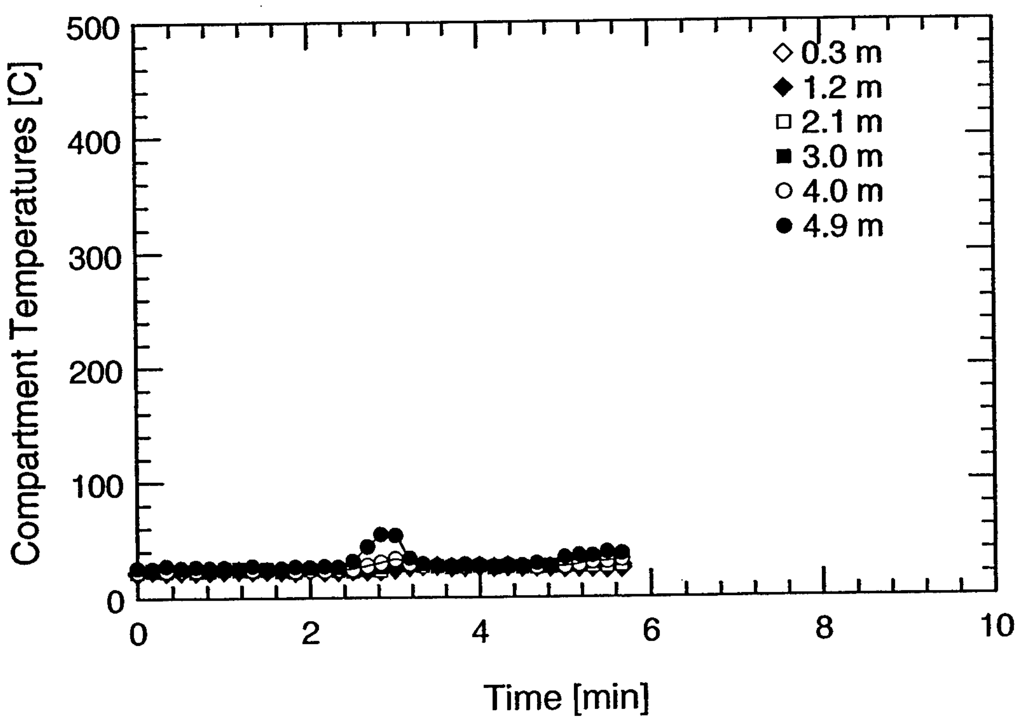


5-27-1

Test #2

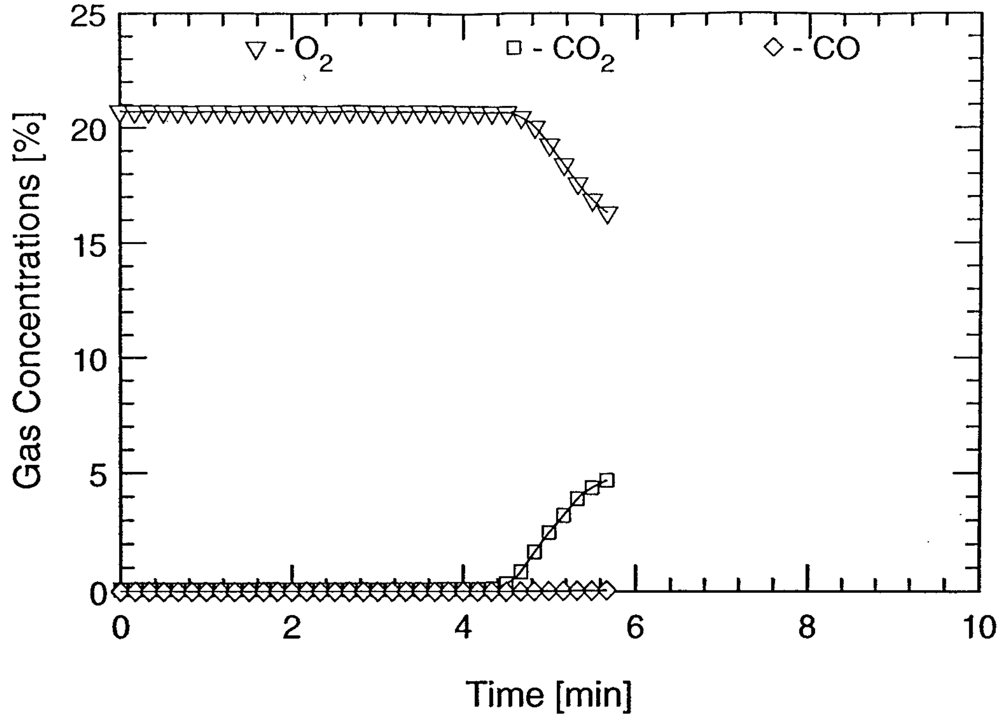


5-27-2

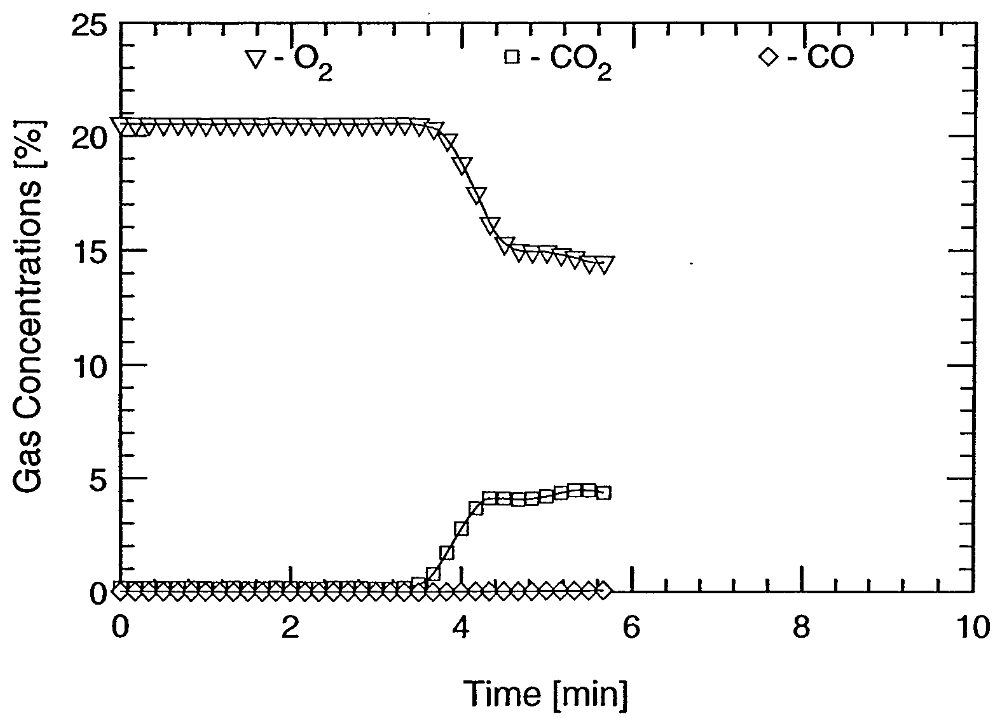


5-35-1

Test #2

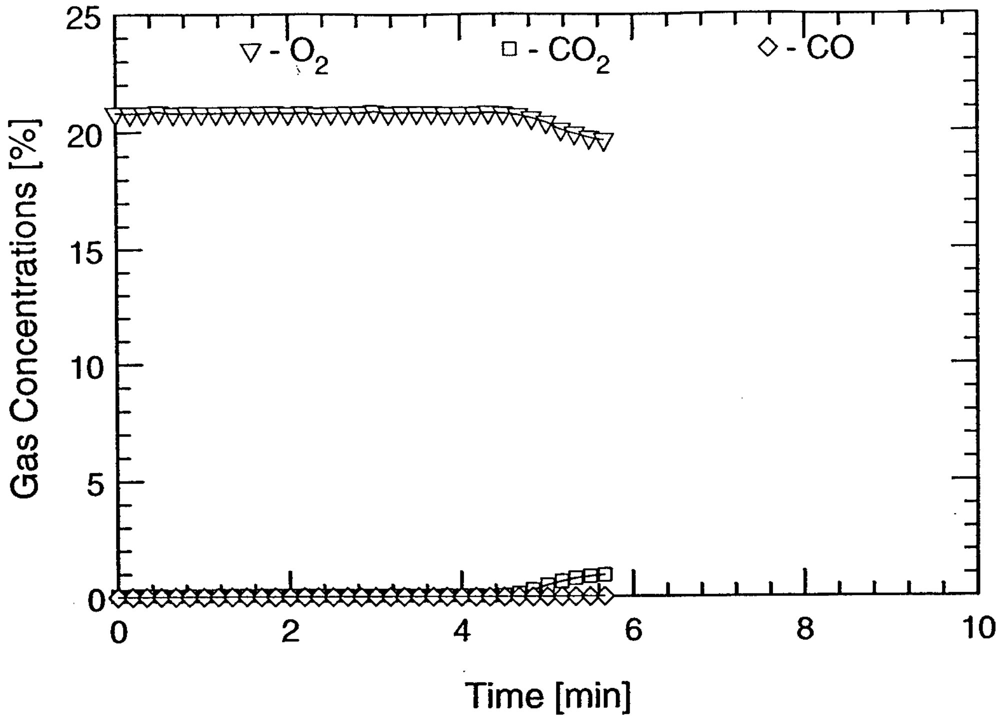


FR 22 - 0.5 m

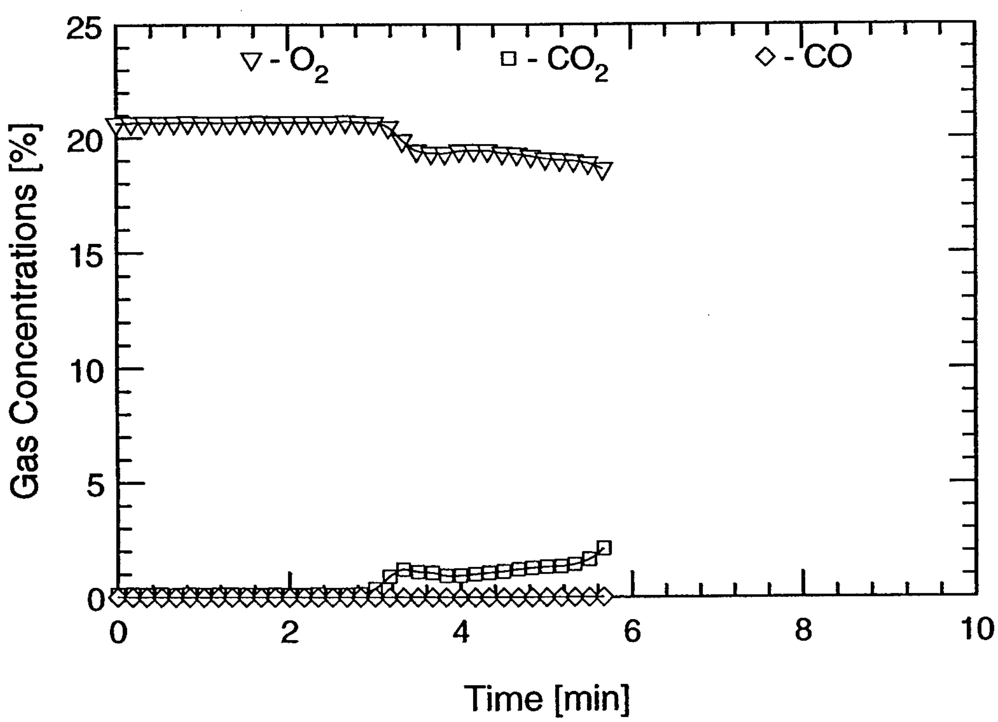


FR 22 - 4.5 m

Test #2

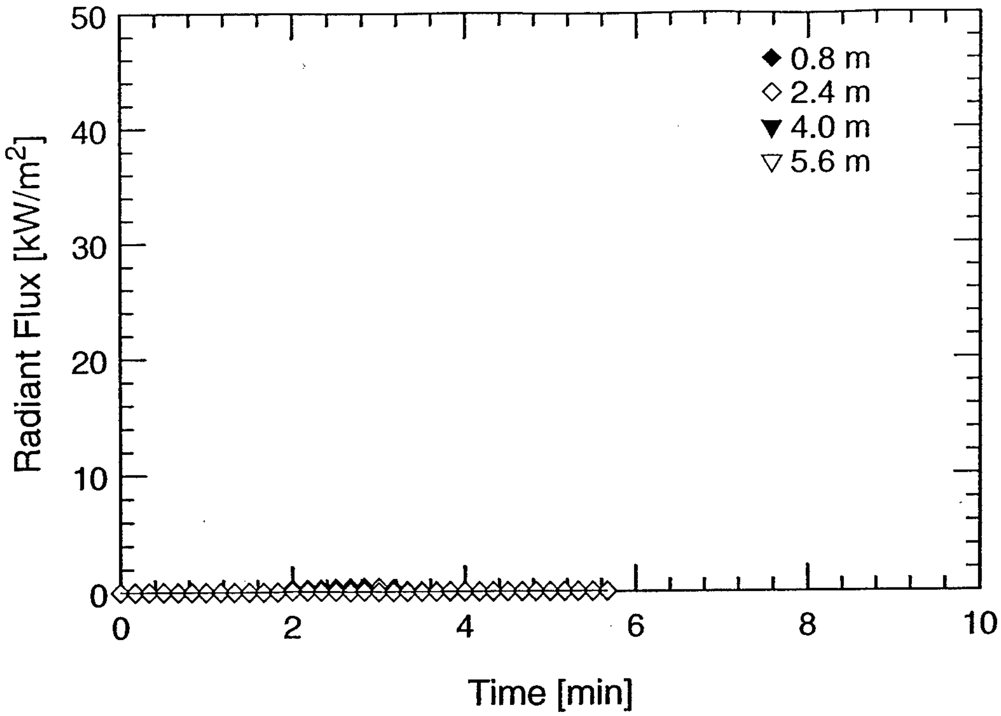


FR 36 - 0.5 m

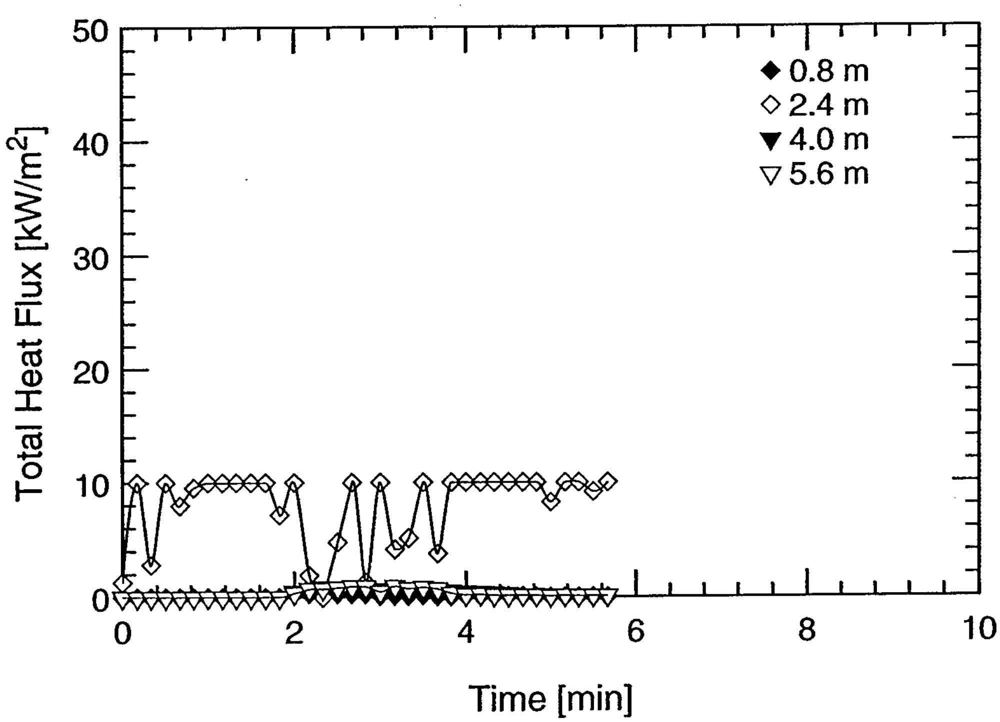


FR 36 - 4.5 m

Test #2

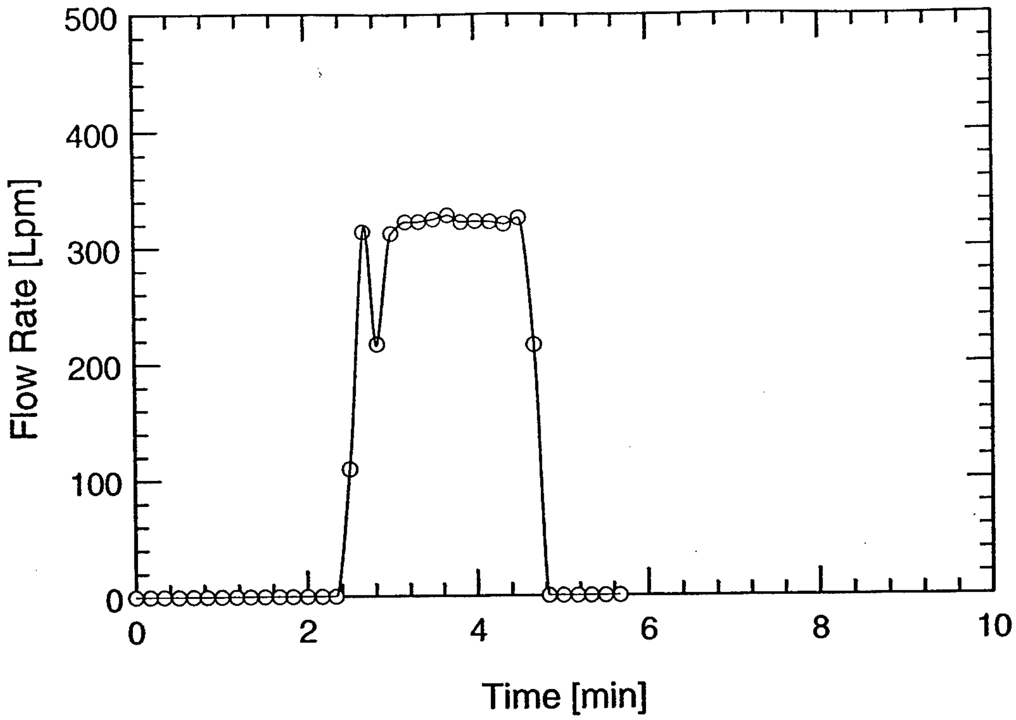


FR 22

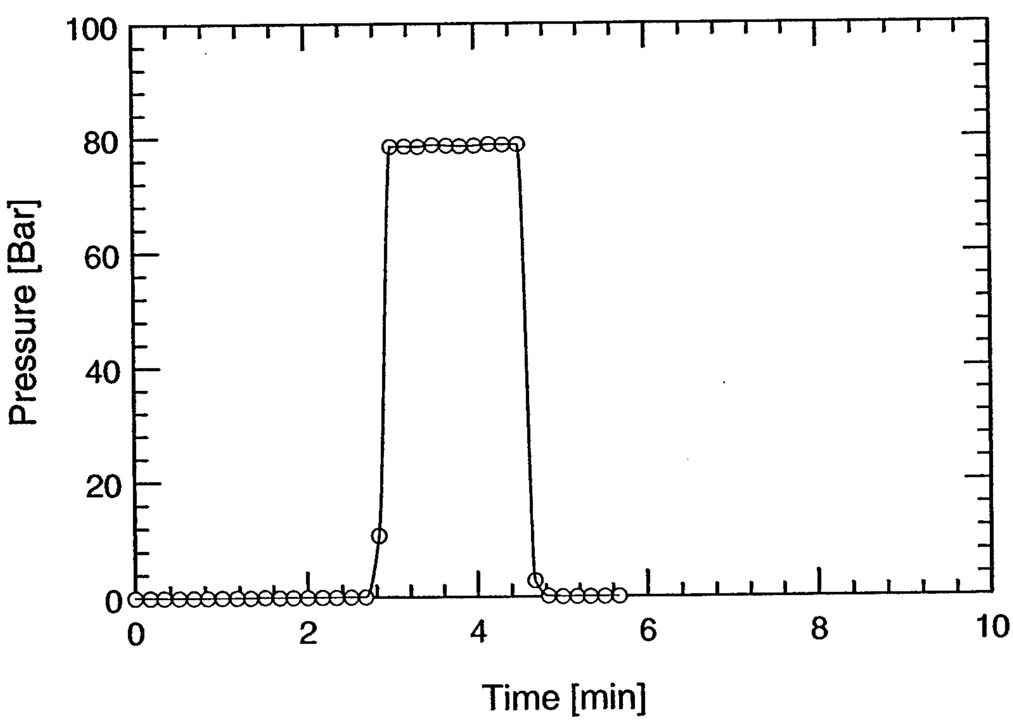


FR 22

Test #2

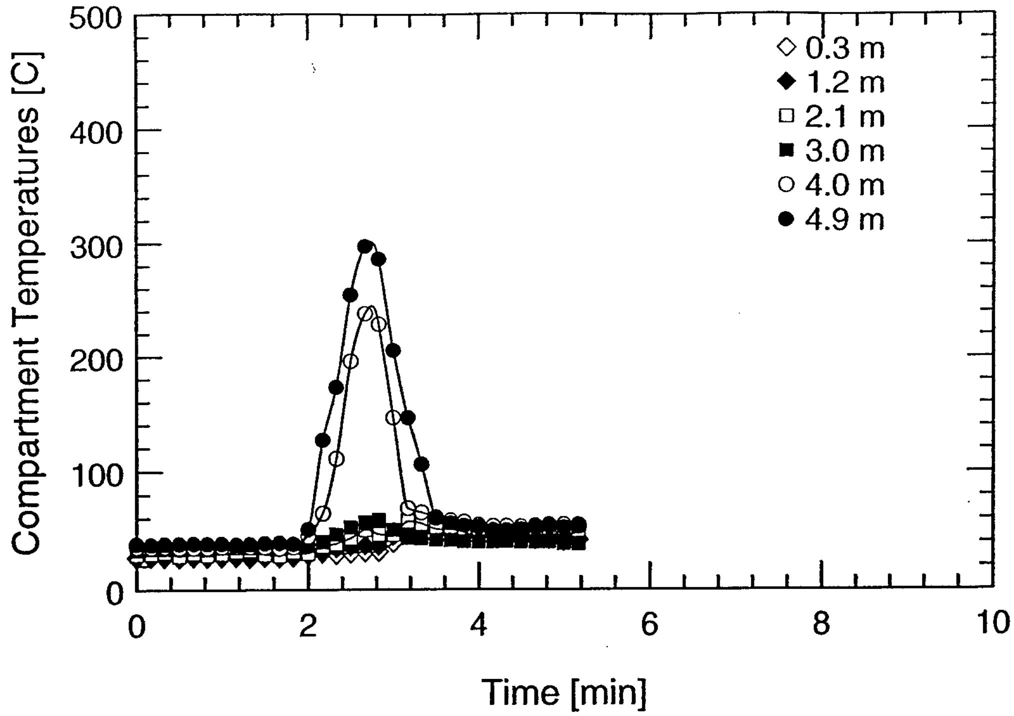


Water Mist System Flow Rate

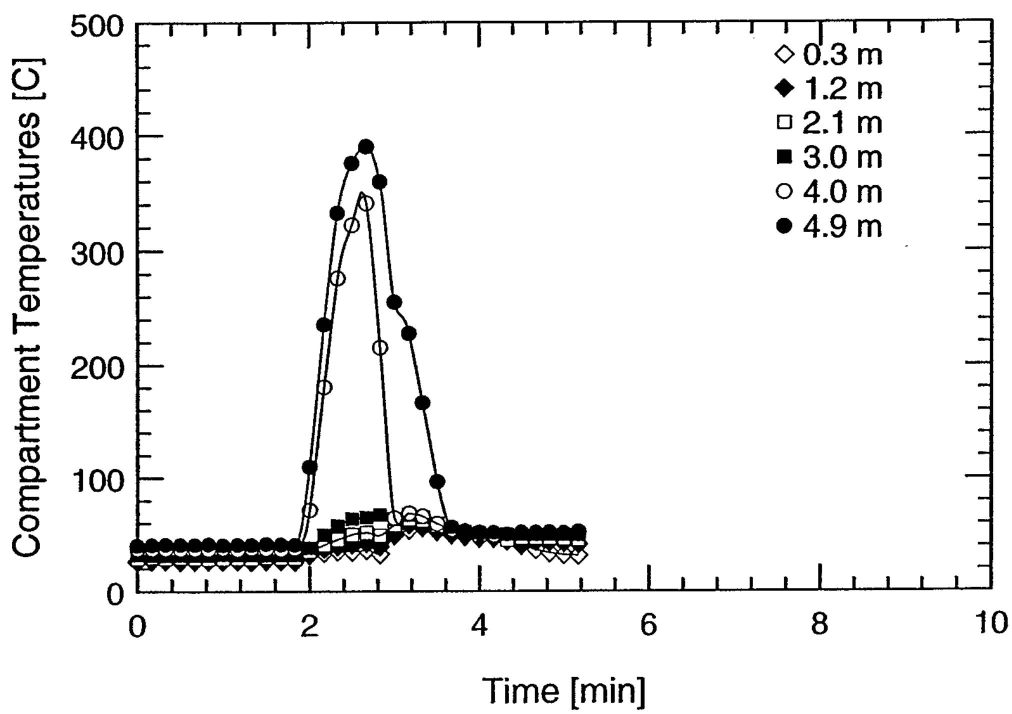


Water Mist System Pressure

Test #2

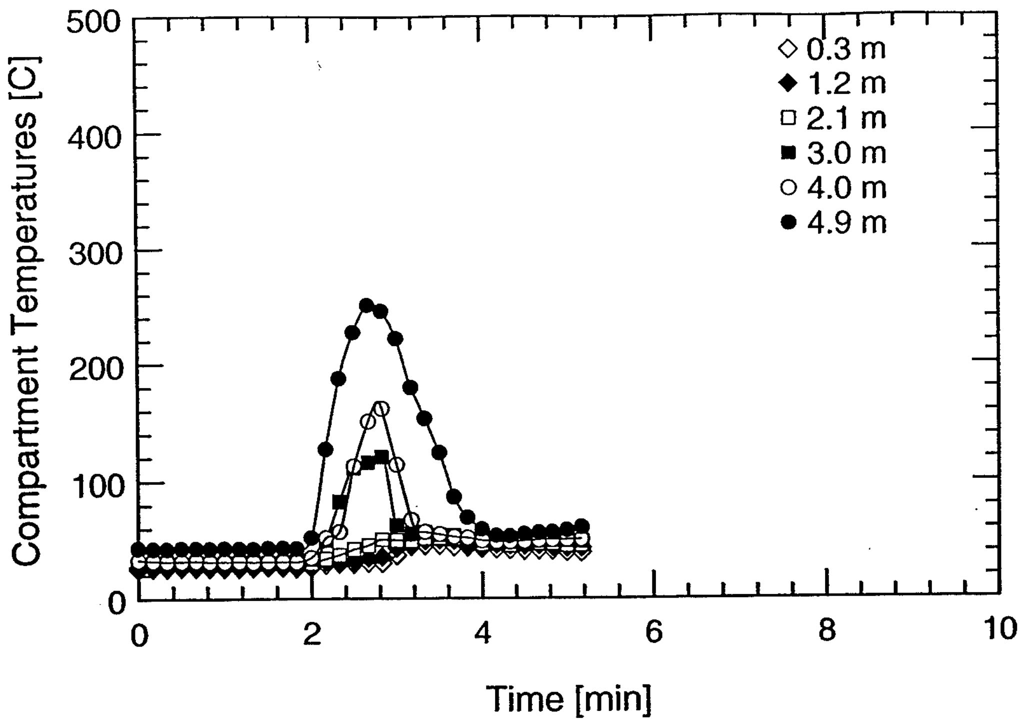


5-22-1

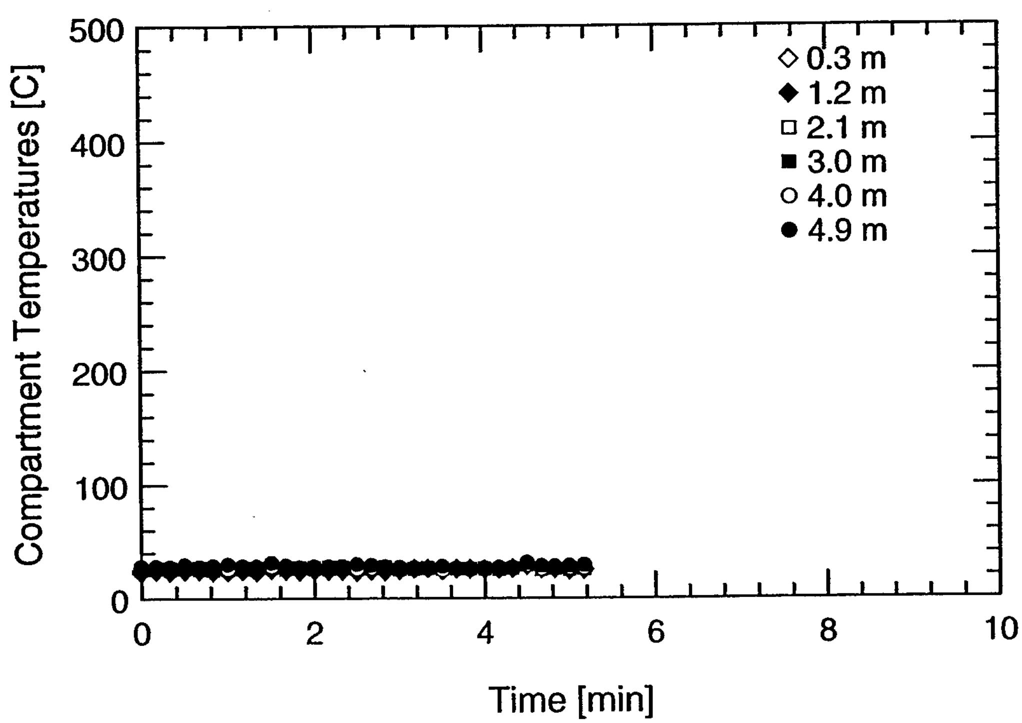


5-27-1

Test #3

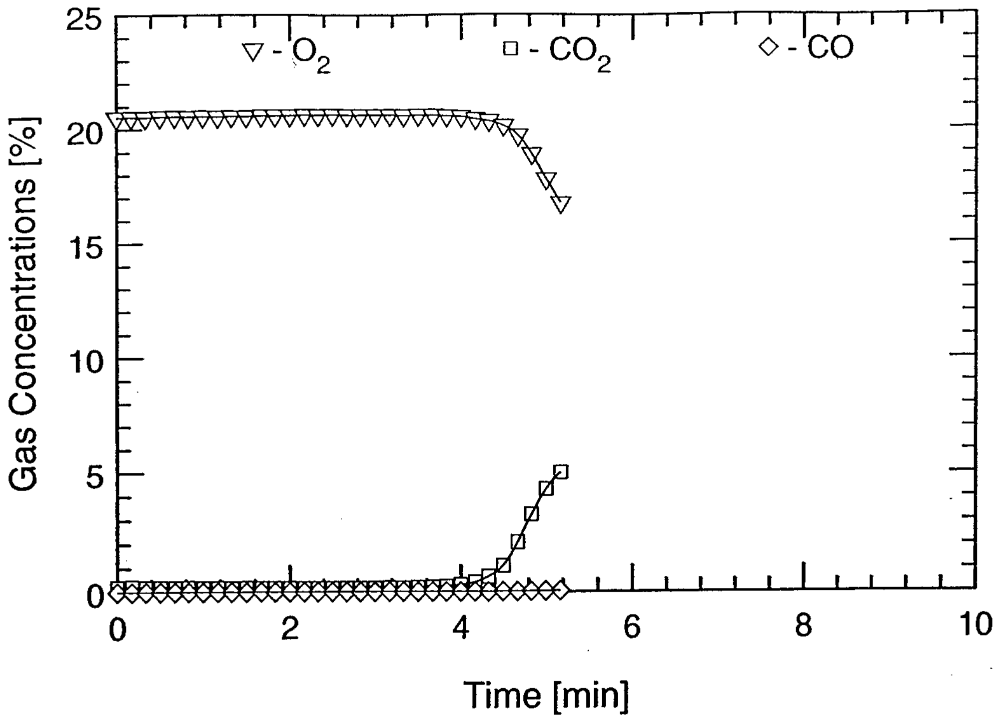


5-27-2

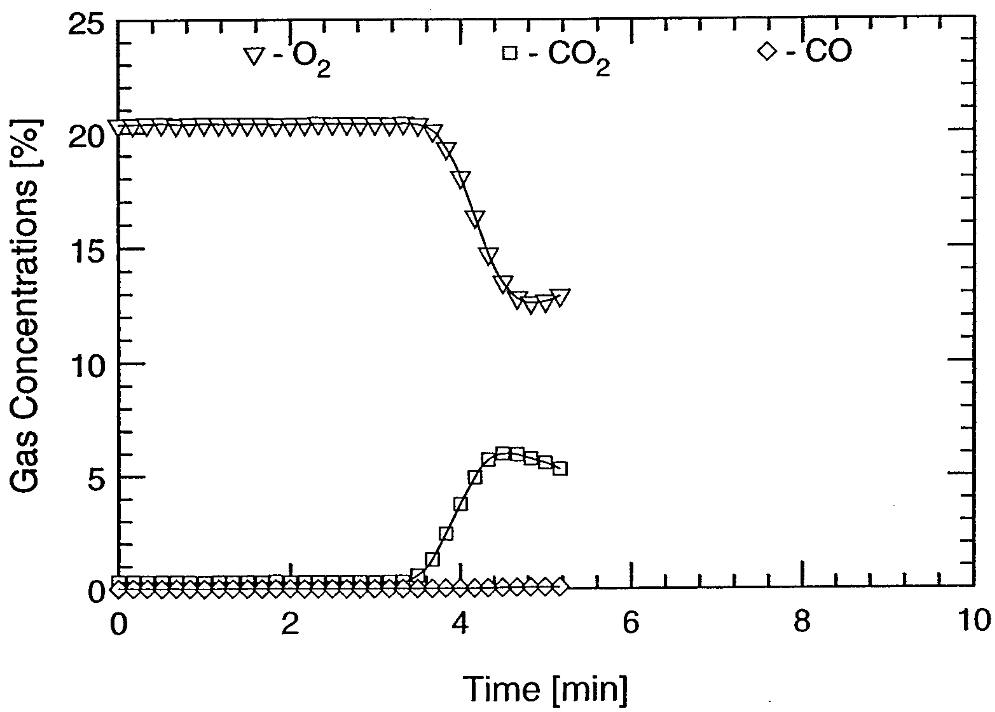


5-35-1

Test #3

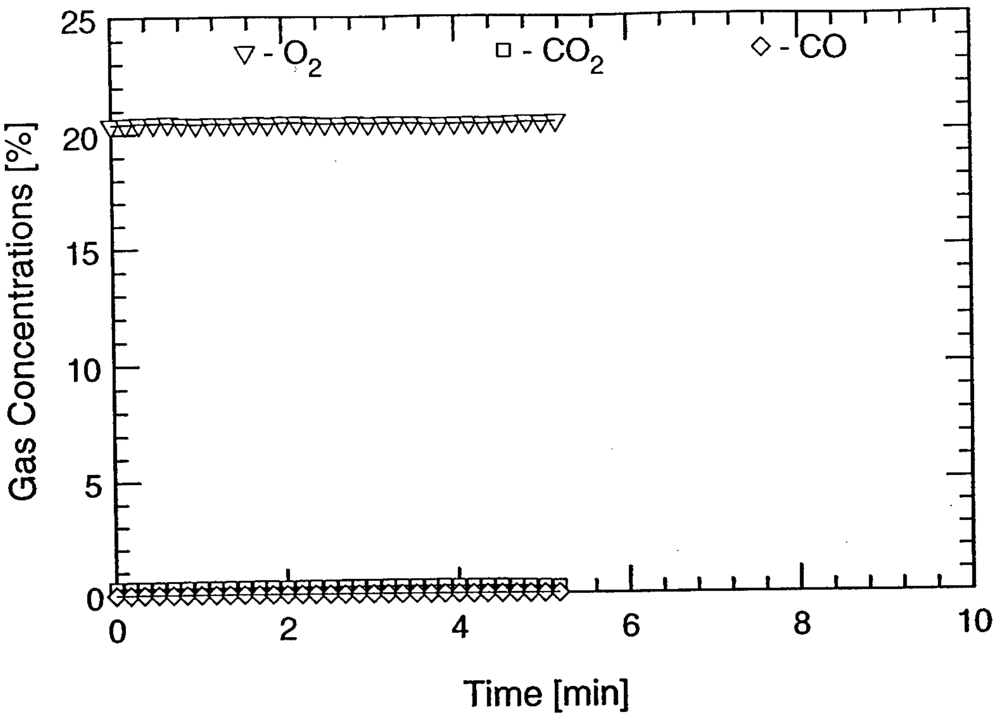


FR 22 - 0.5 m

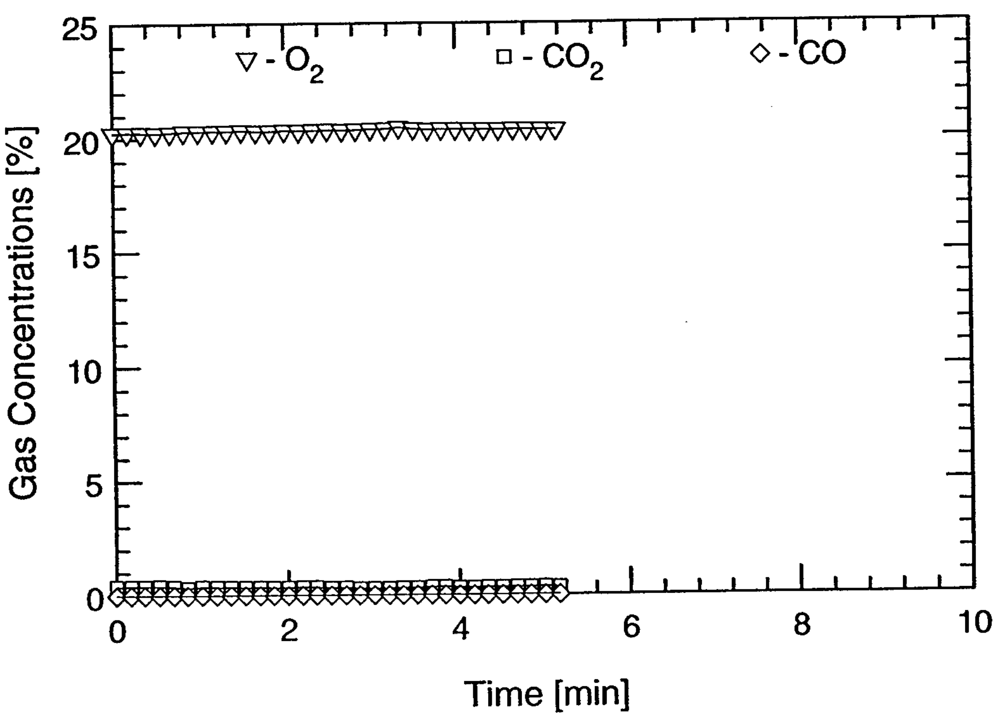


FR 22 - 4.5 m

Test #3

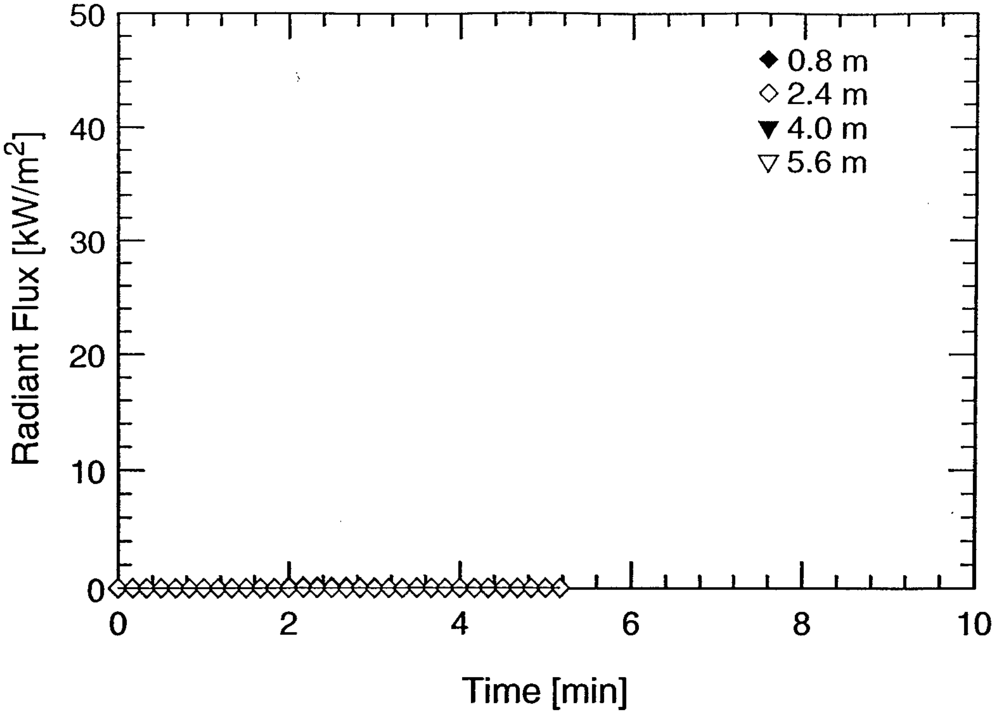


FR 36 - 0.5 m

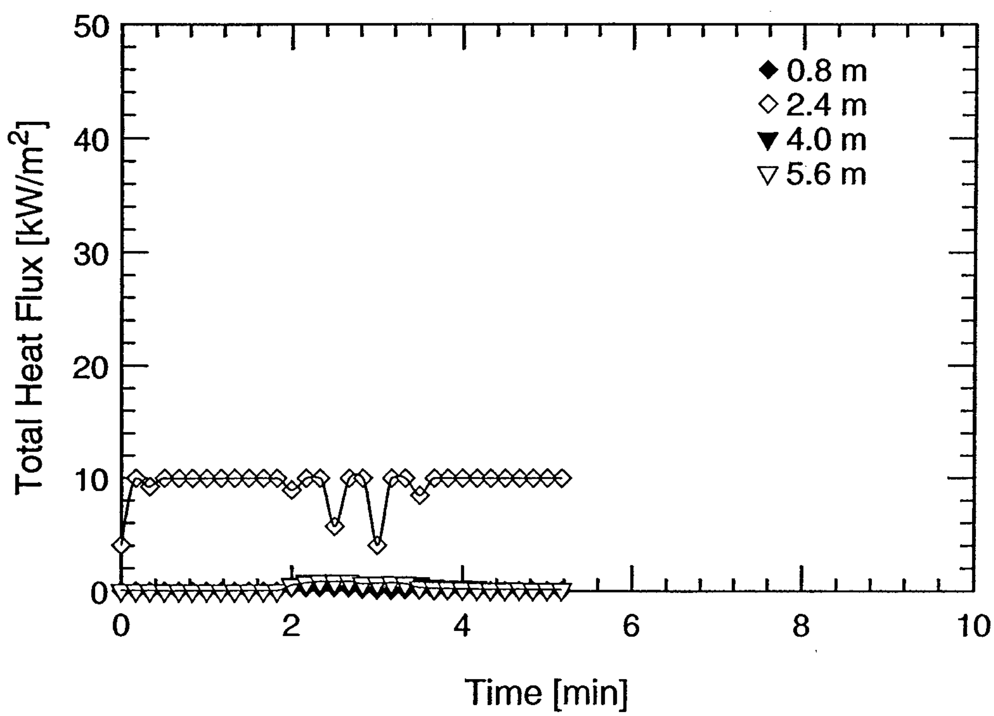


FR 36 - 4.5 m

Test #3

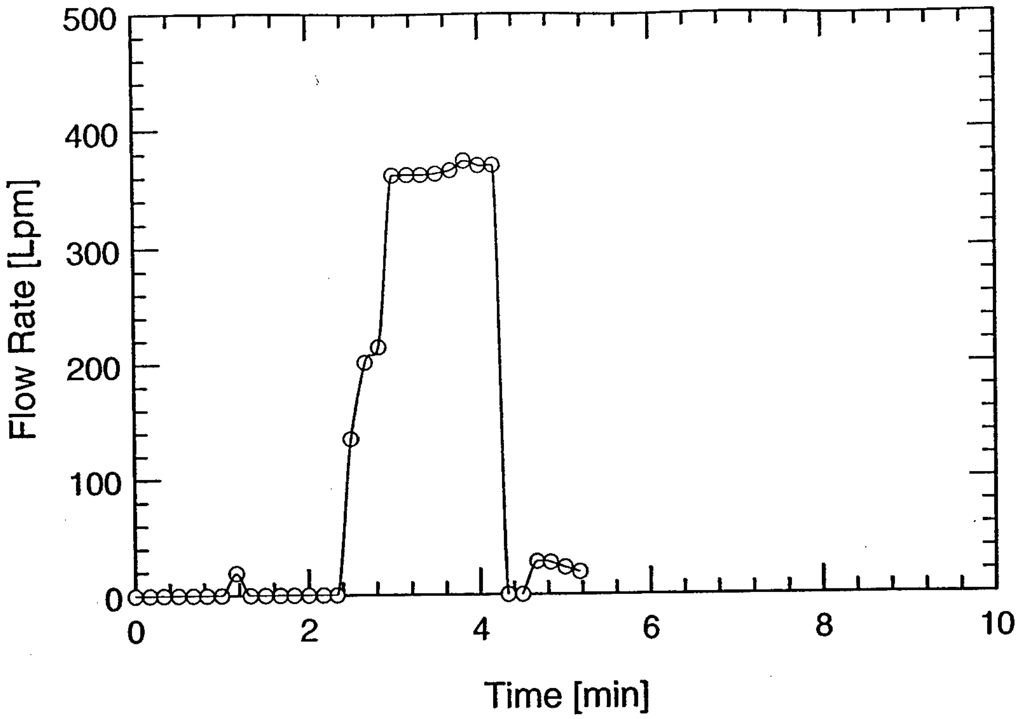


FR 22

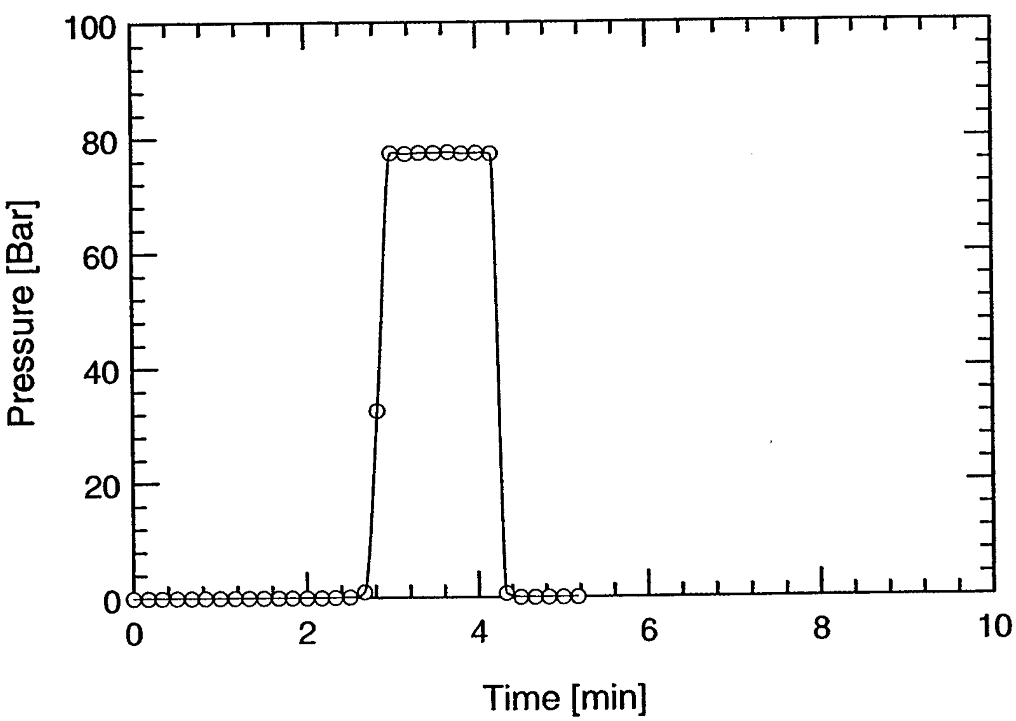


FR 22

Test #3

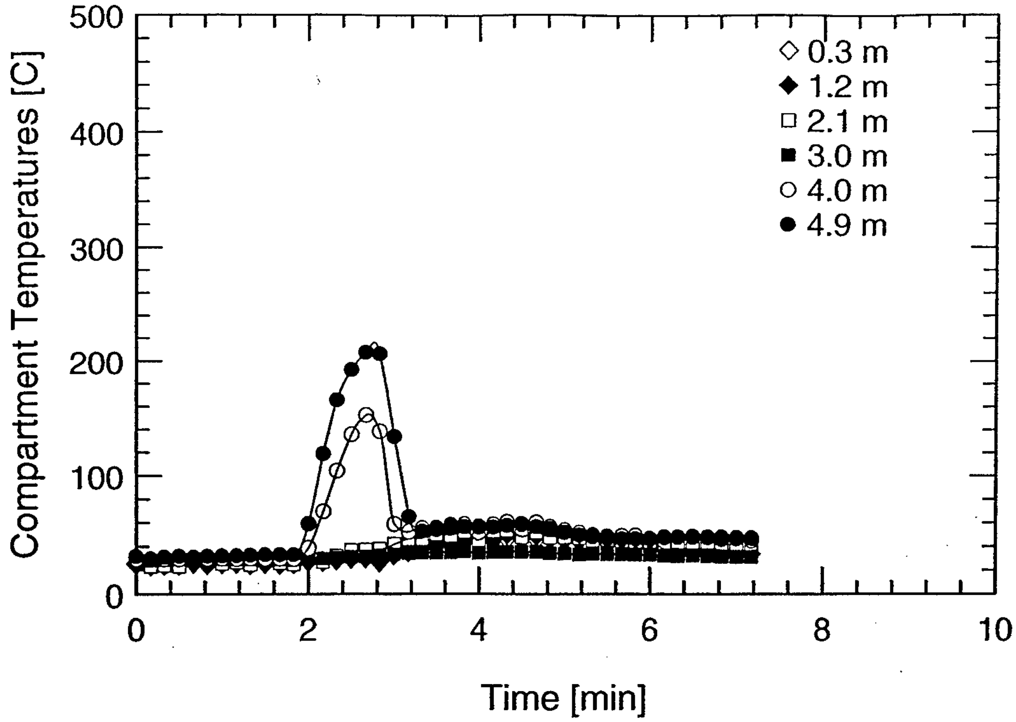


Water Mist System Flow Rate

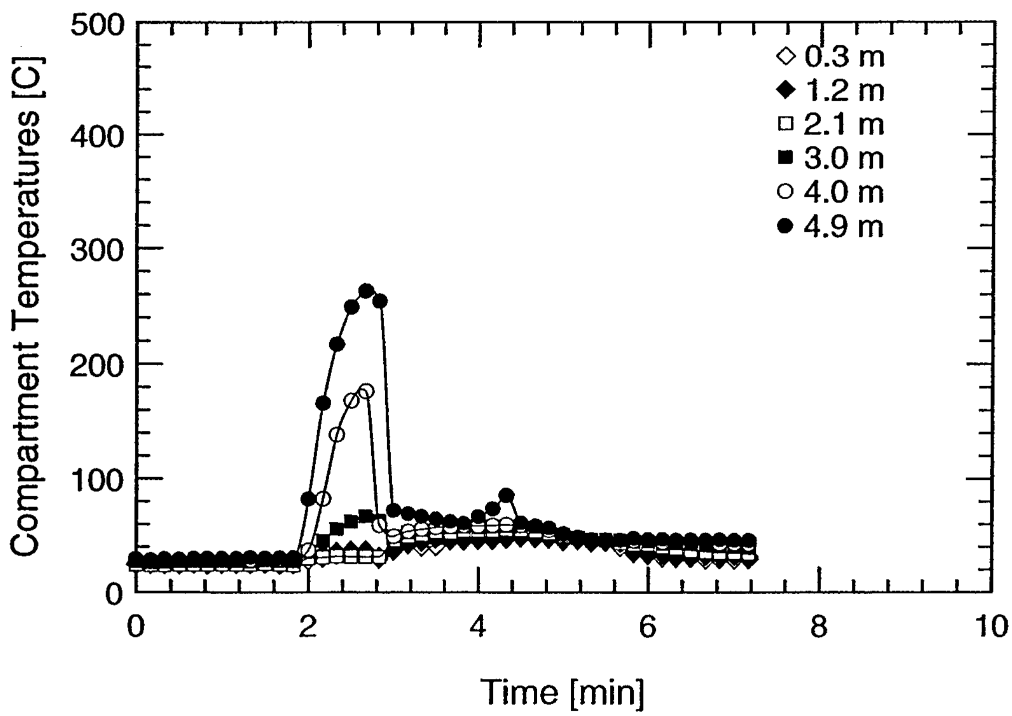


Water Mist System Pressure

Test #3

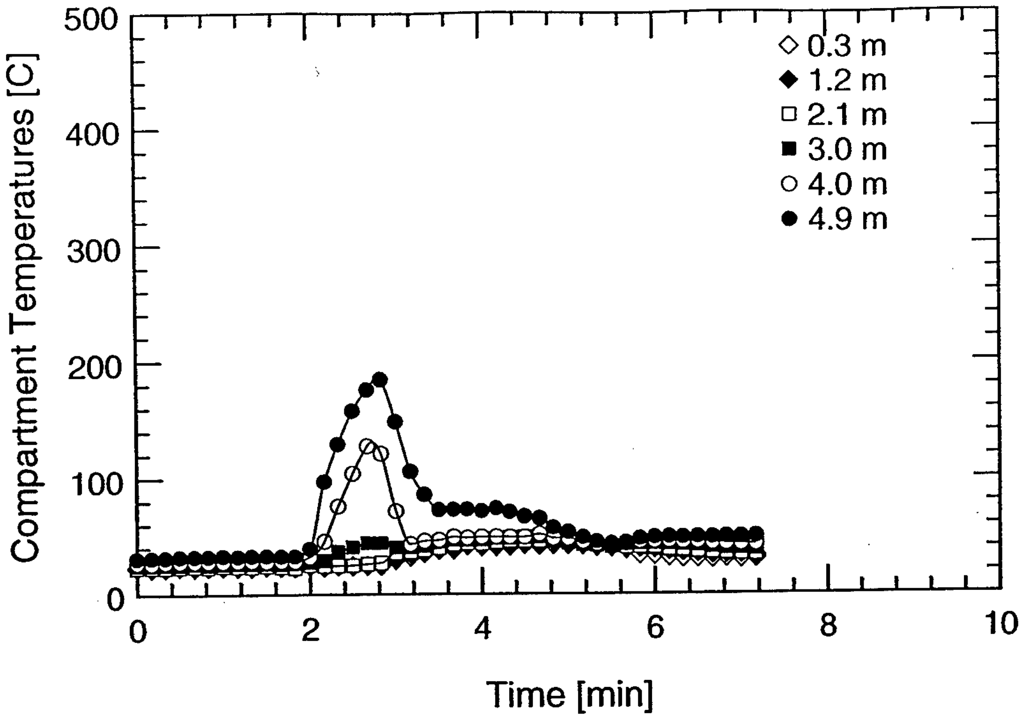


5-22-1

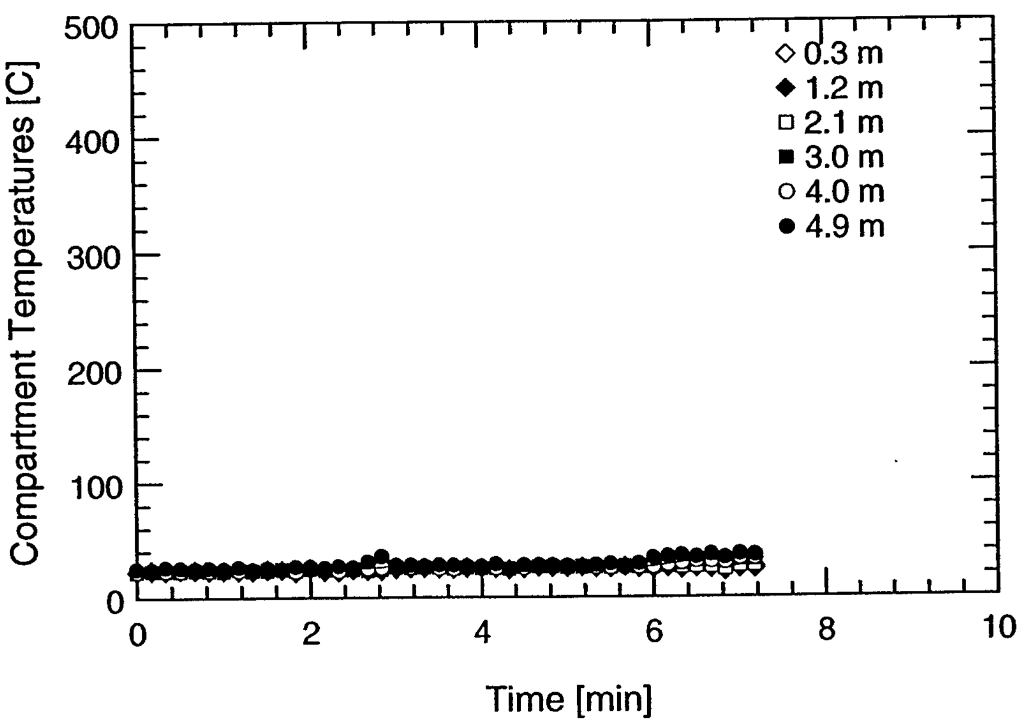


5-27-1

Test #4

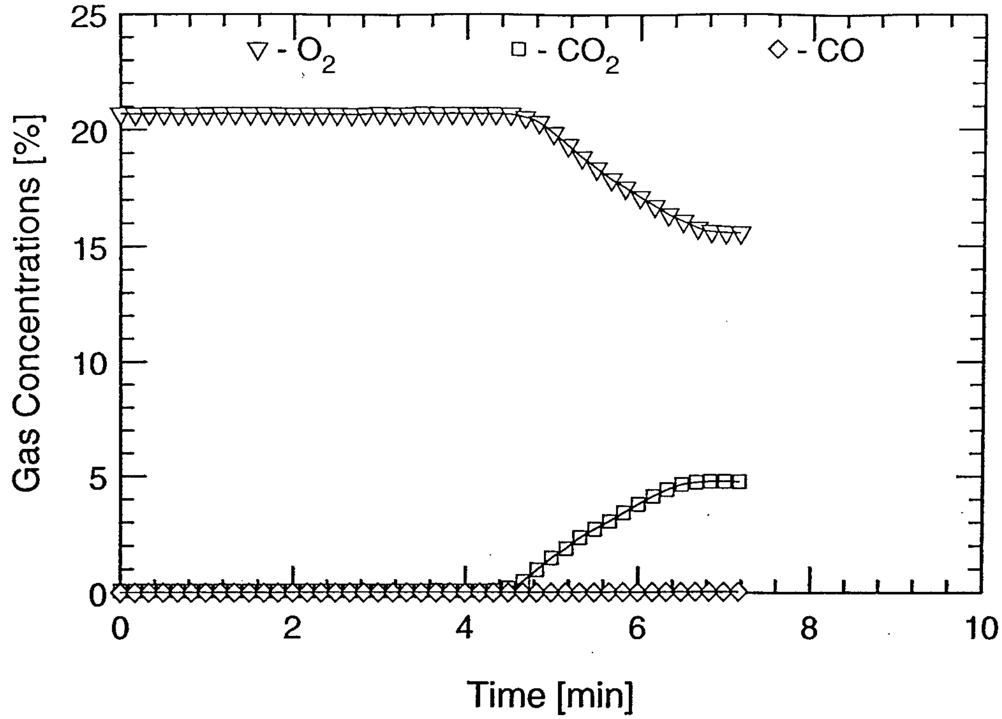


5-27-2

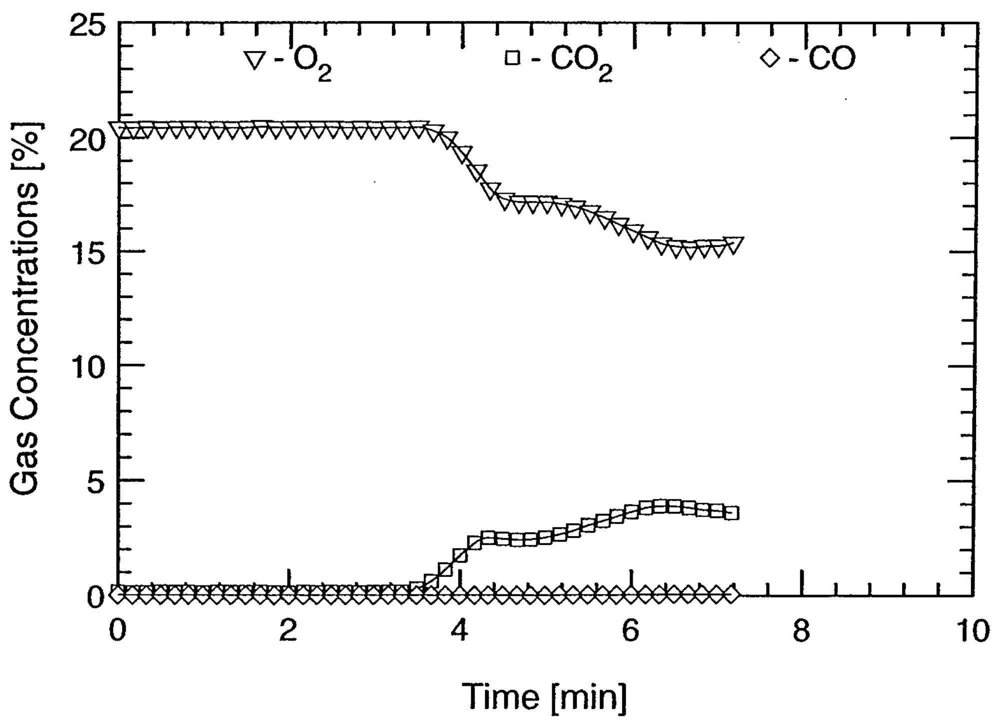


5-35-1

Test #4

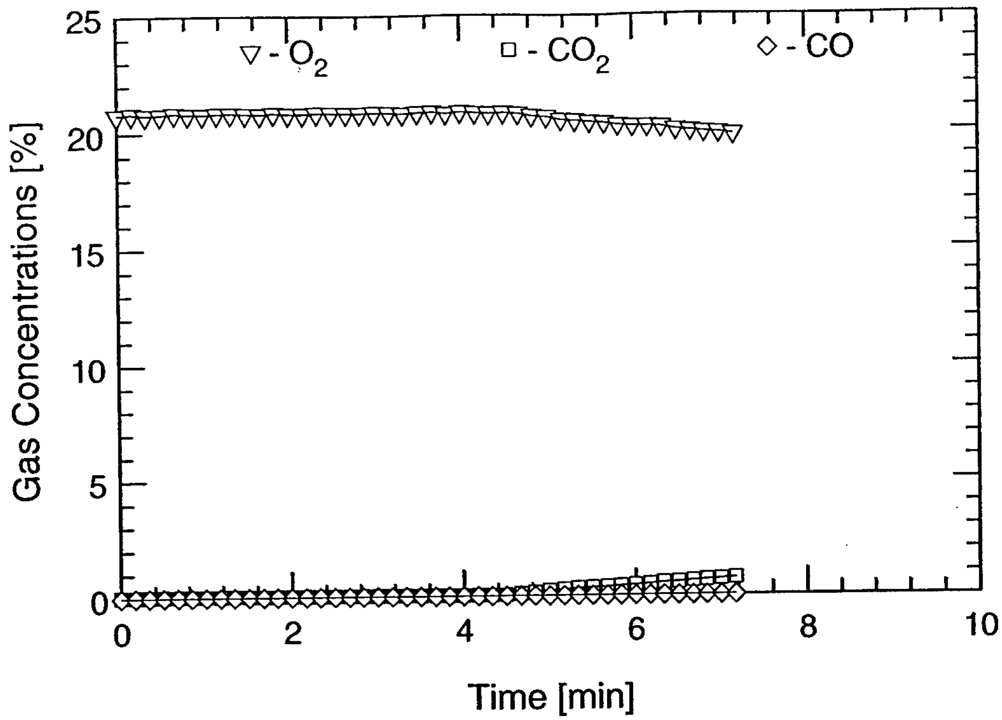


FR 22 - 0.5 m

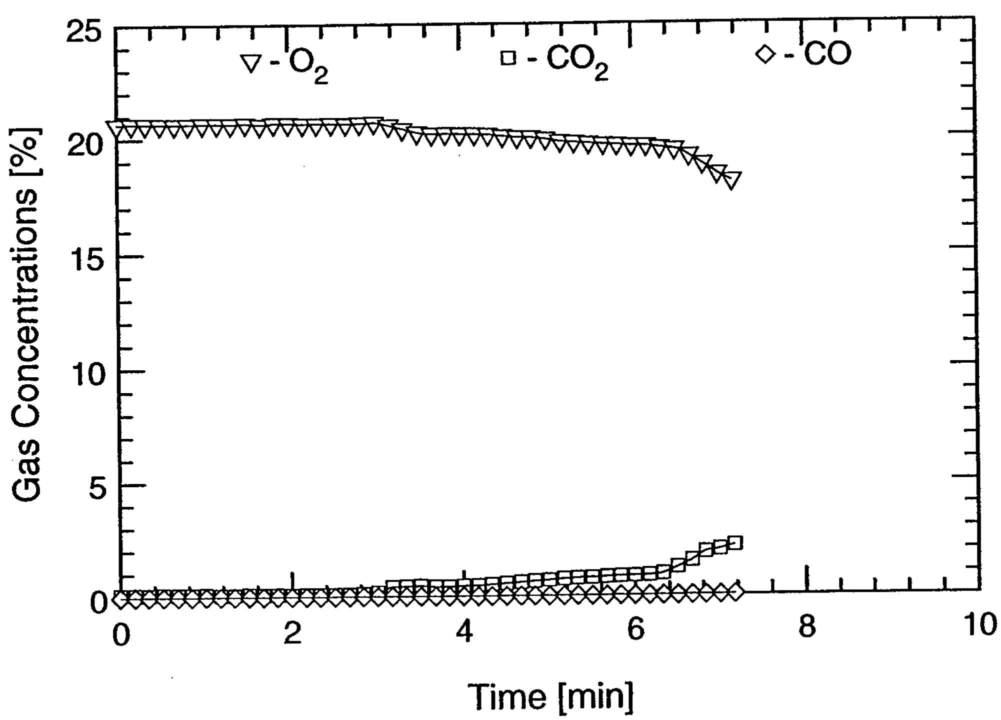


FR 22 - 4.5 m

Test #4

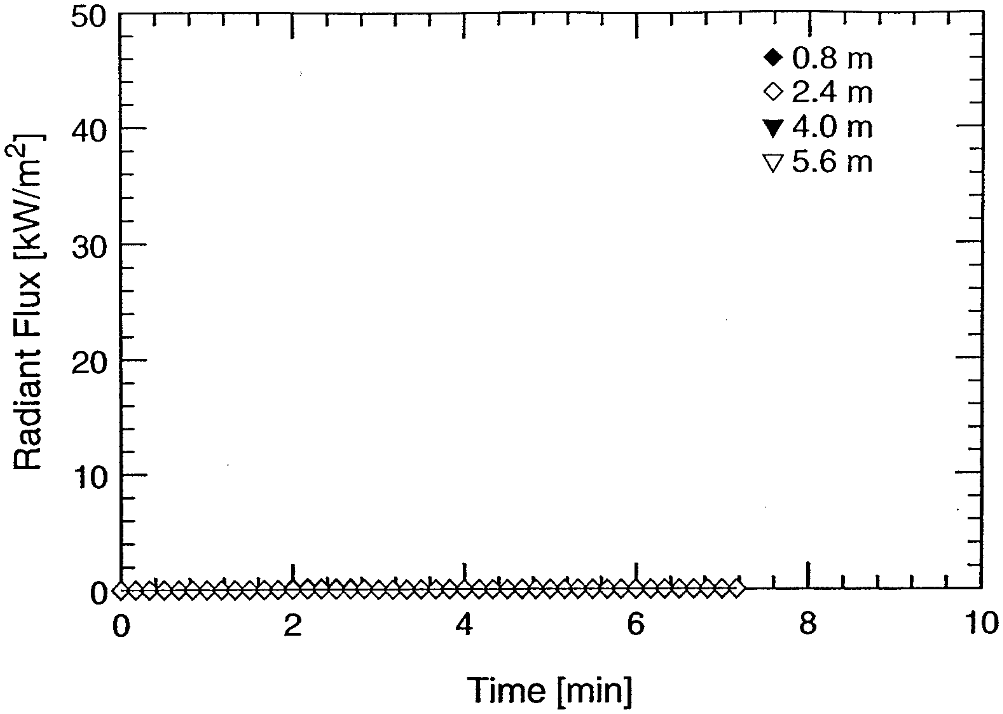


FR 36 - 0.5 m

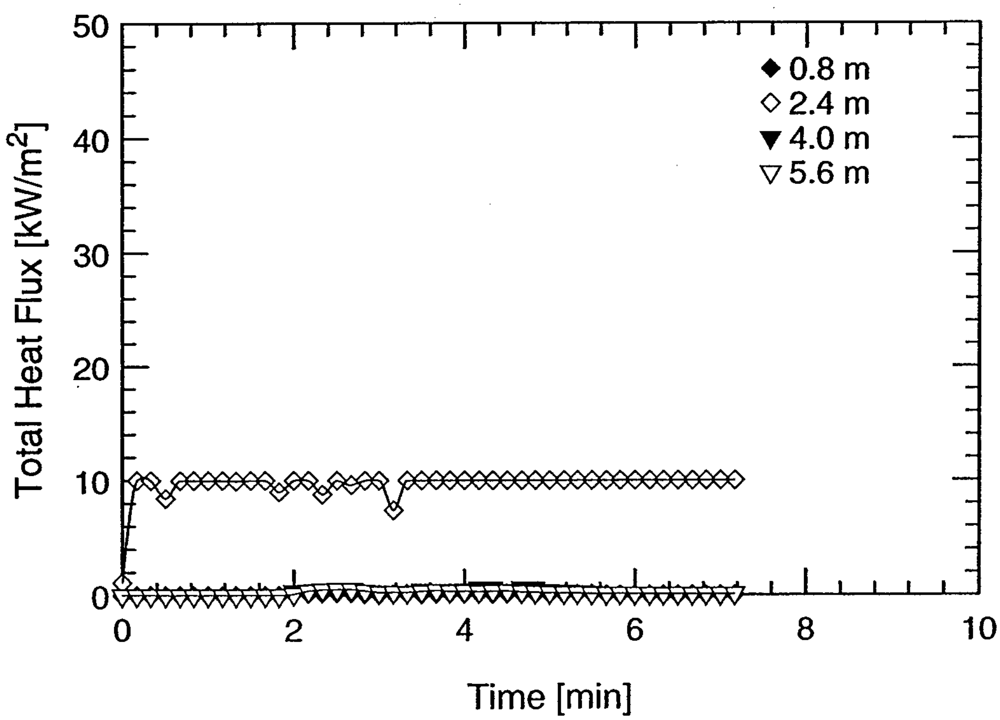


FR 36 - 4.5 m

Test #4

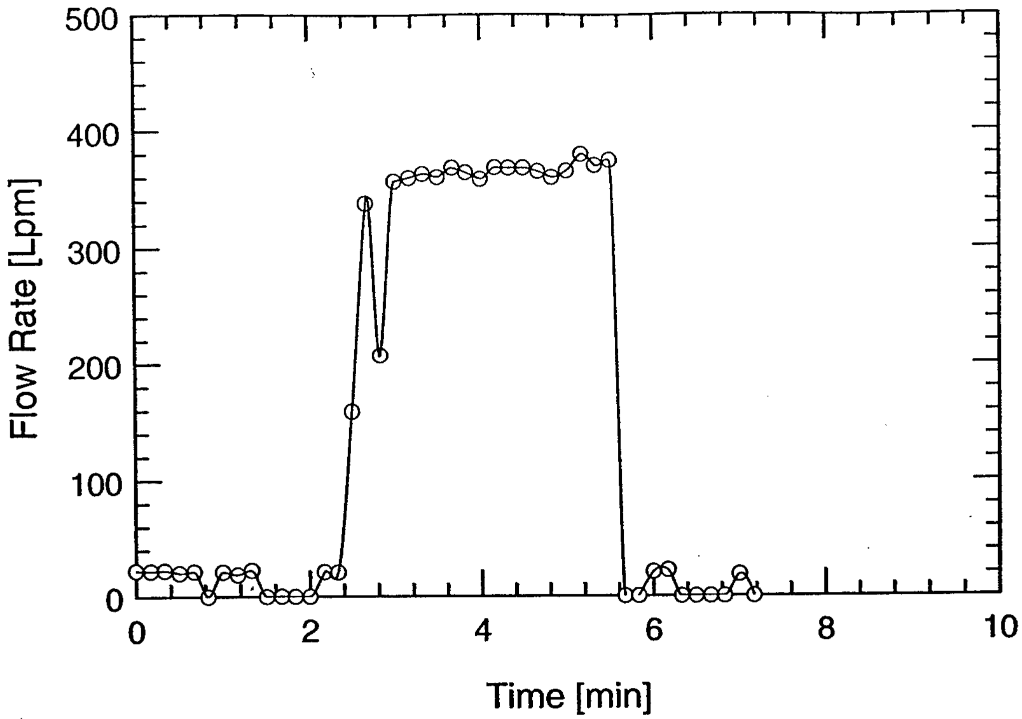


FR 22

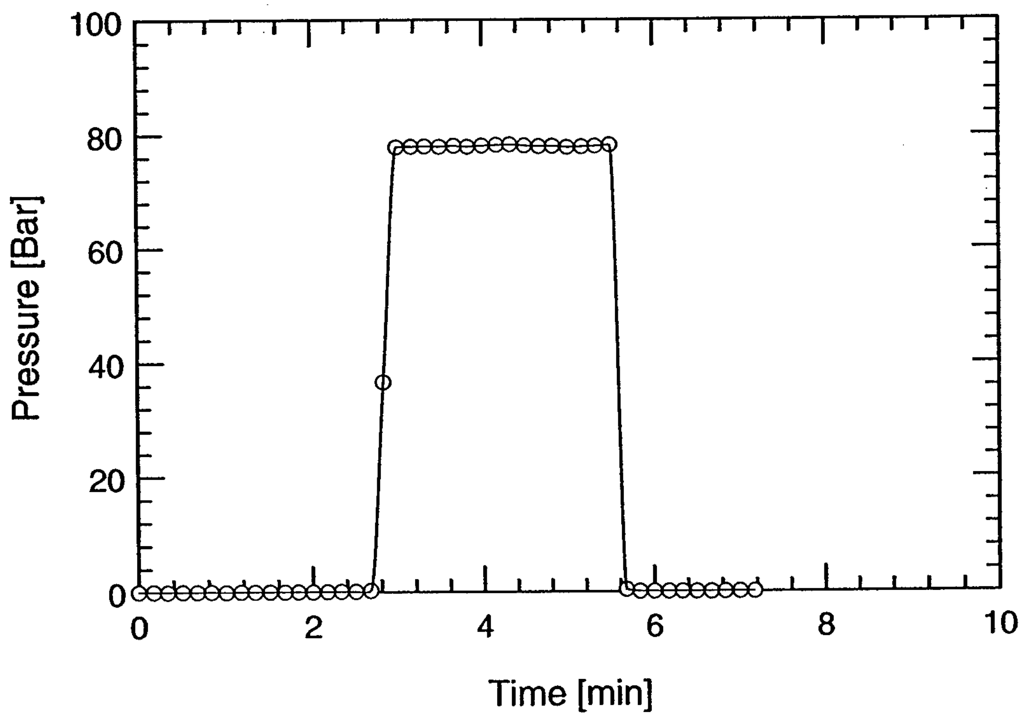


FR 22

Test #4

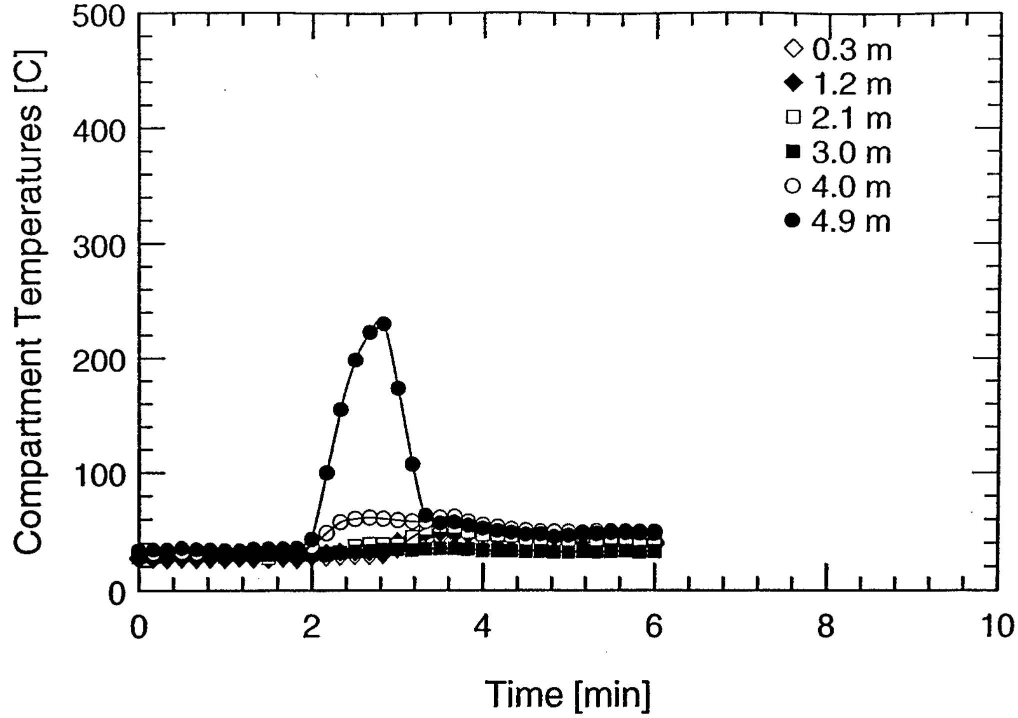


Water Mist System Flow Rate

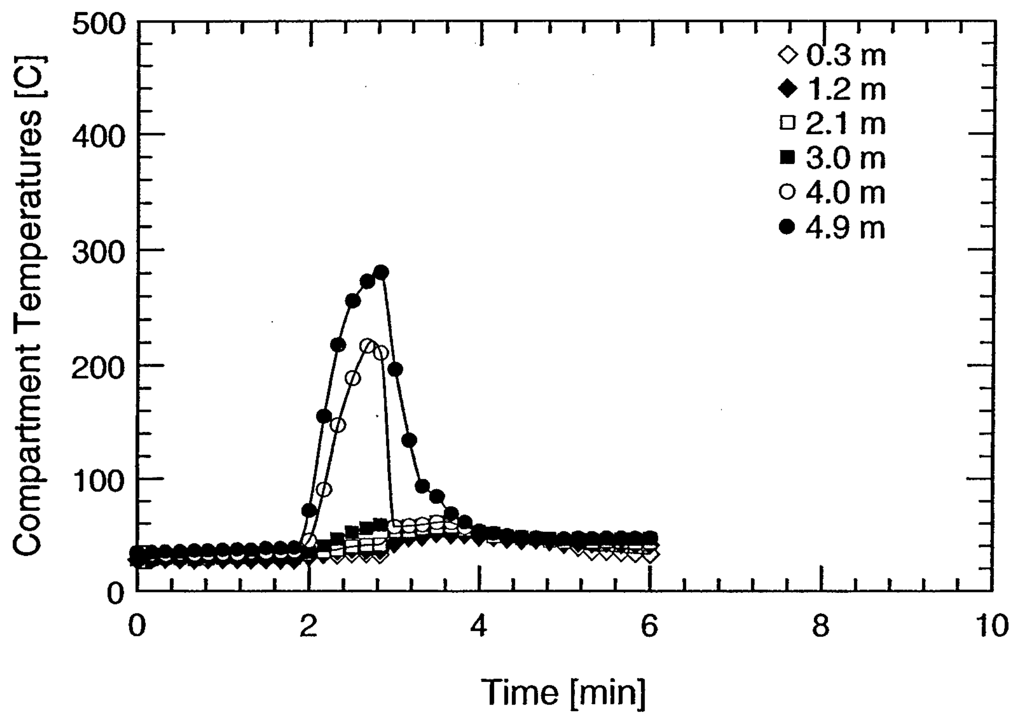


Water Mist System Pressure

Test #4

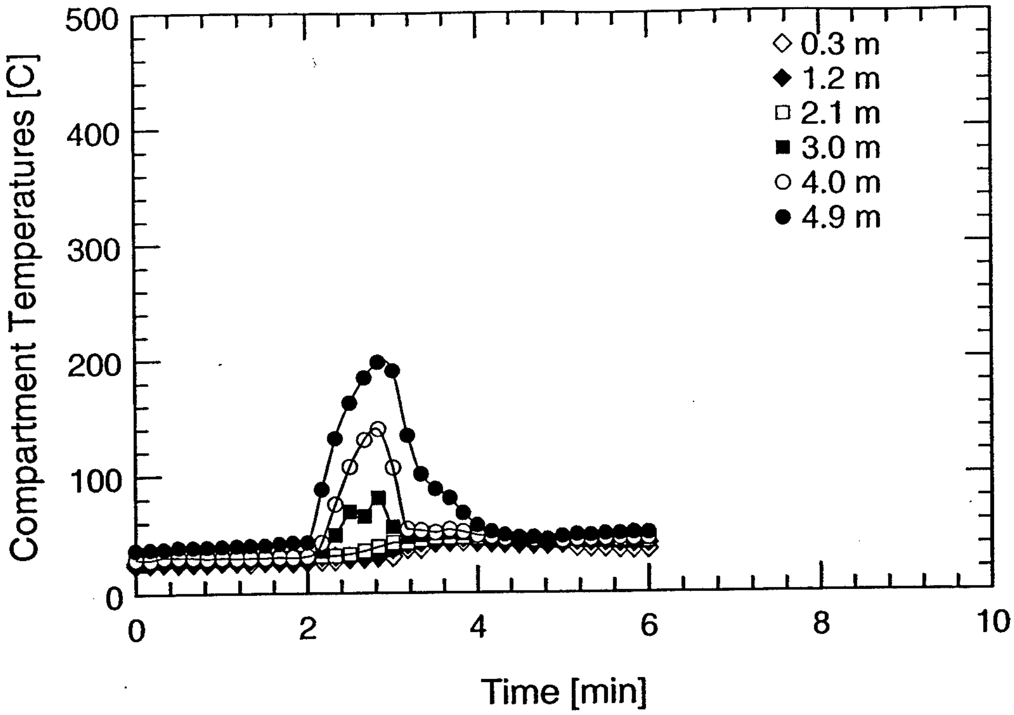


5-22-1

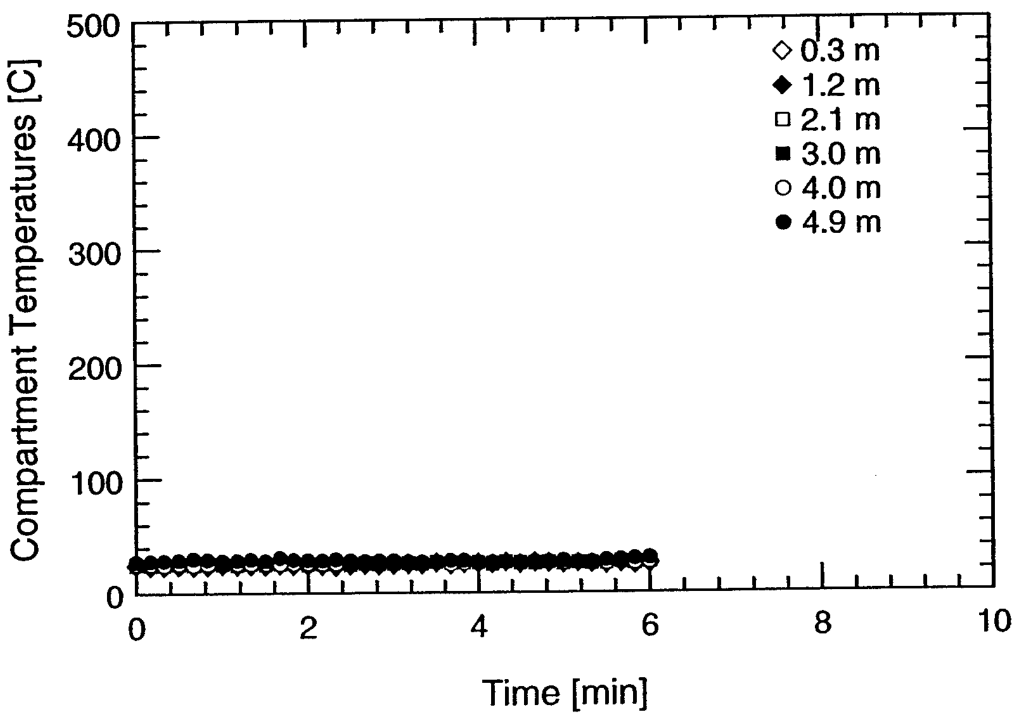


5-27-1

Test #5

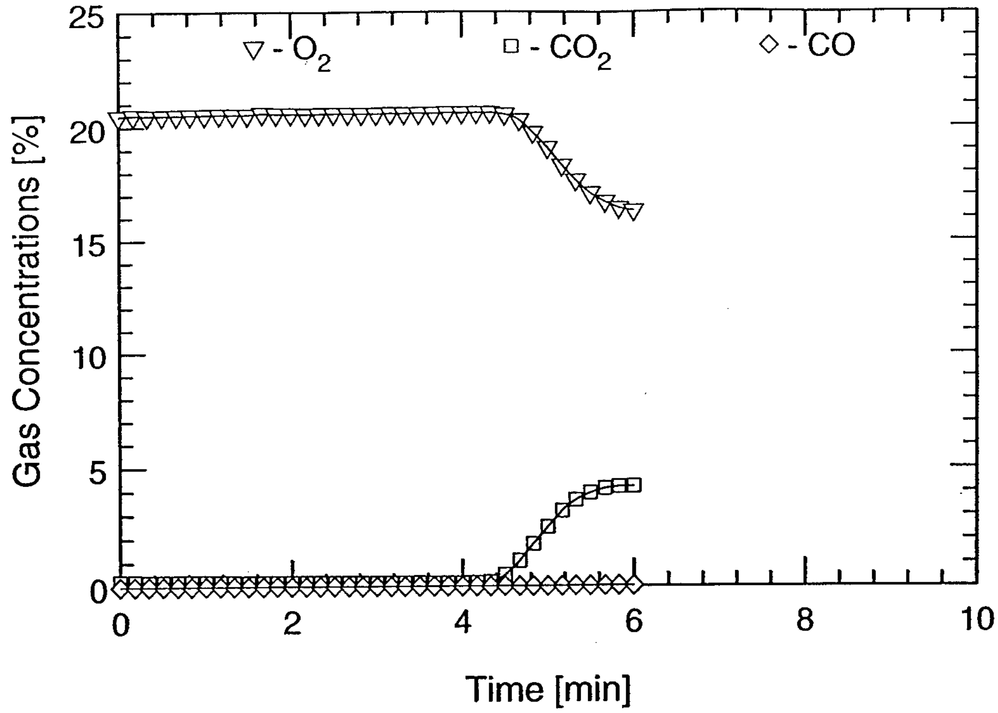


5-27-2

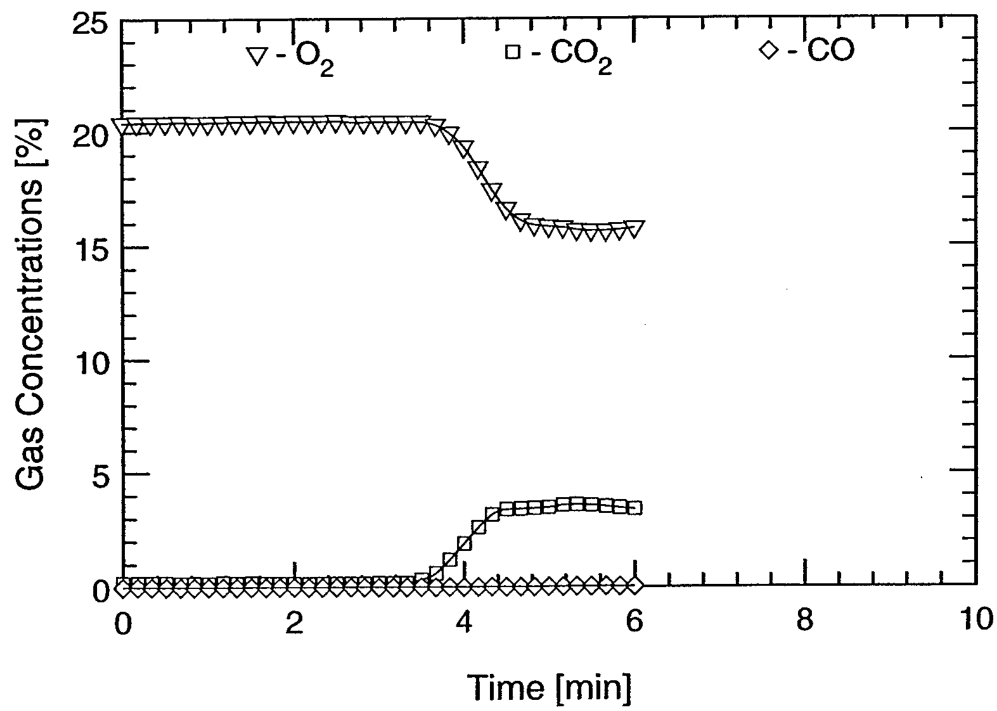


5-35-1

Test #5

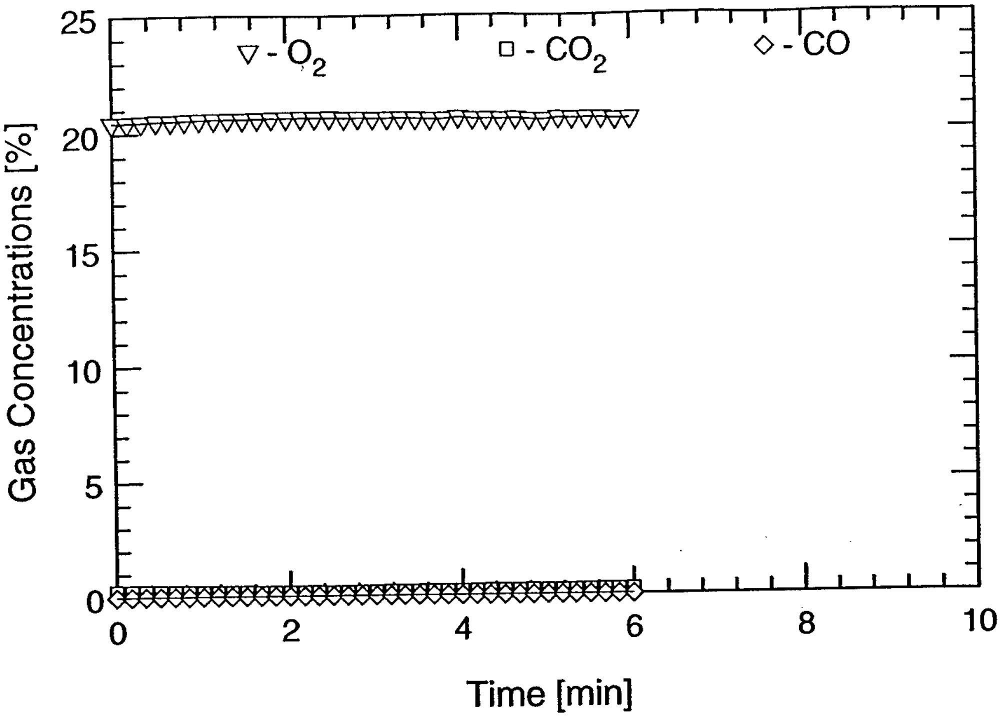


FR 22 - 0.5 m

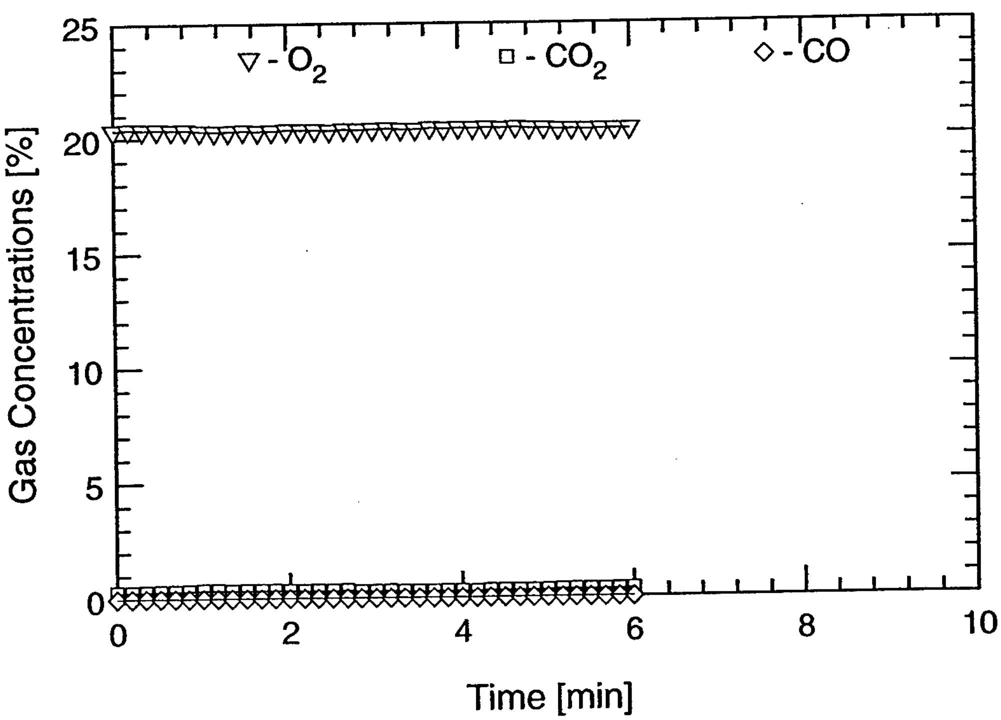


FR 22 - 4.5 m

Test #5

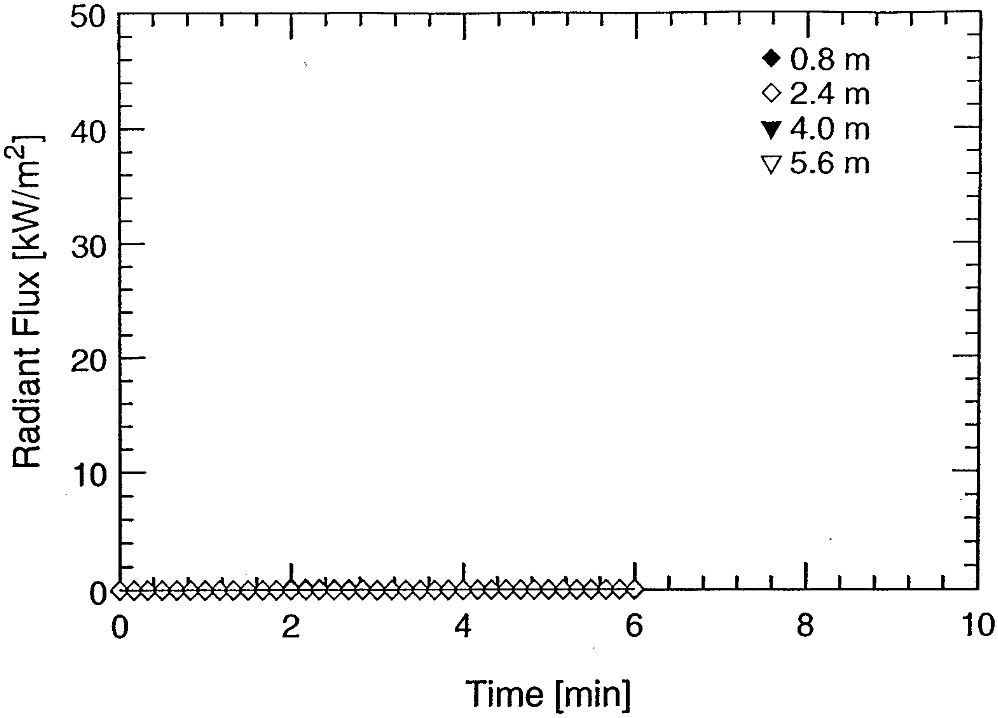


FR 36 - 0.5 m

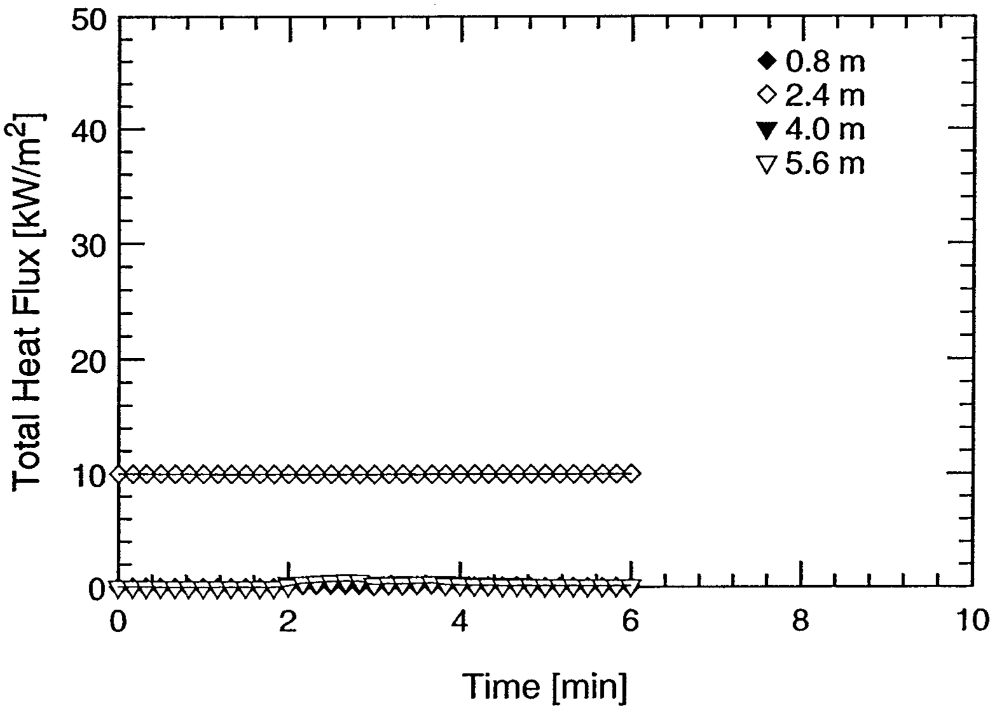


FR 36 - 4.5 m

Test #5

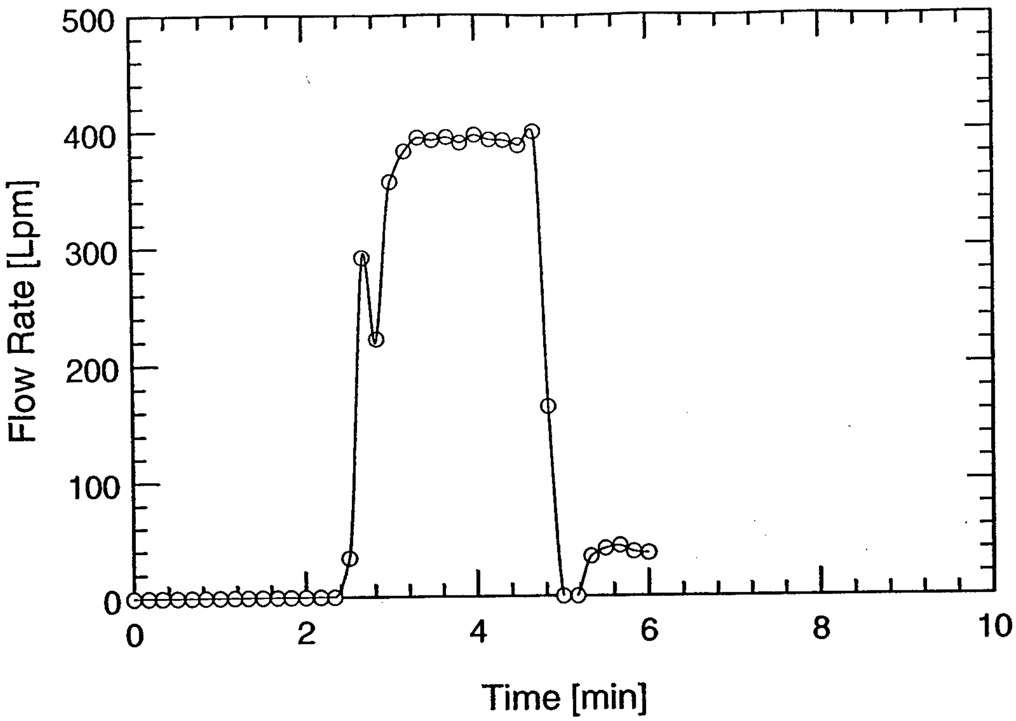


FR 22

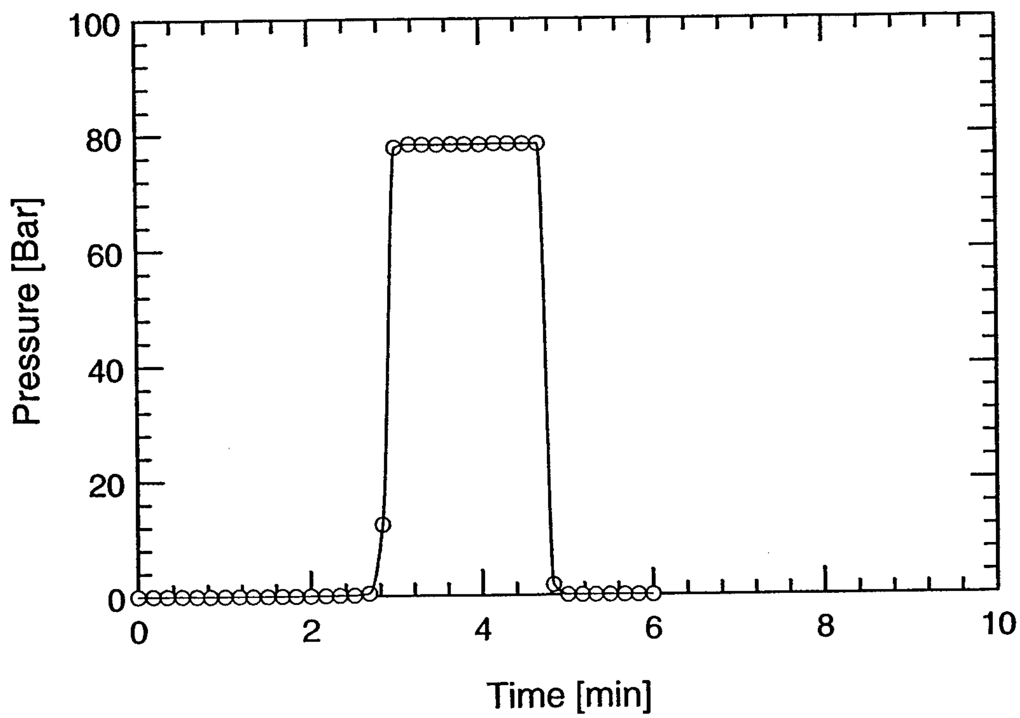


FR 22

Test #5

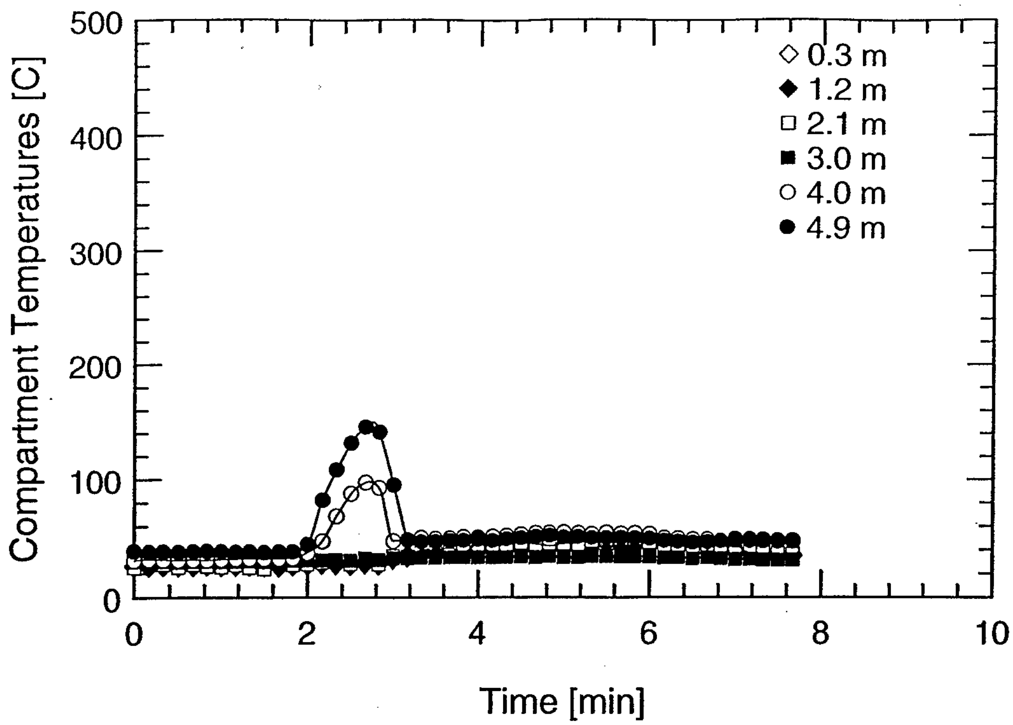


Water Mist System Flow Rate

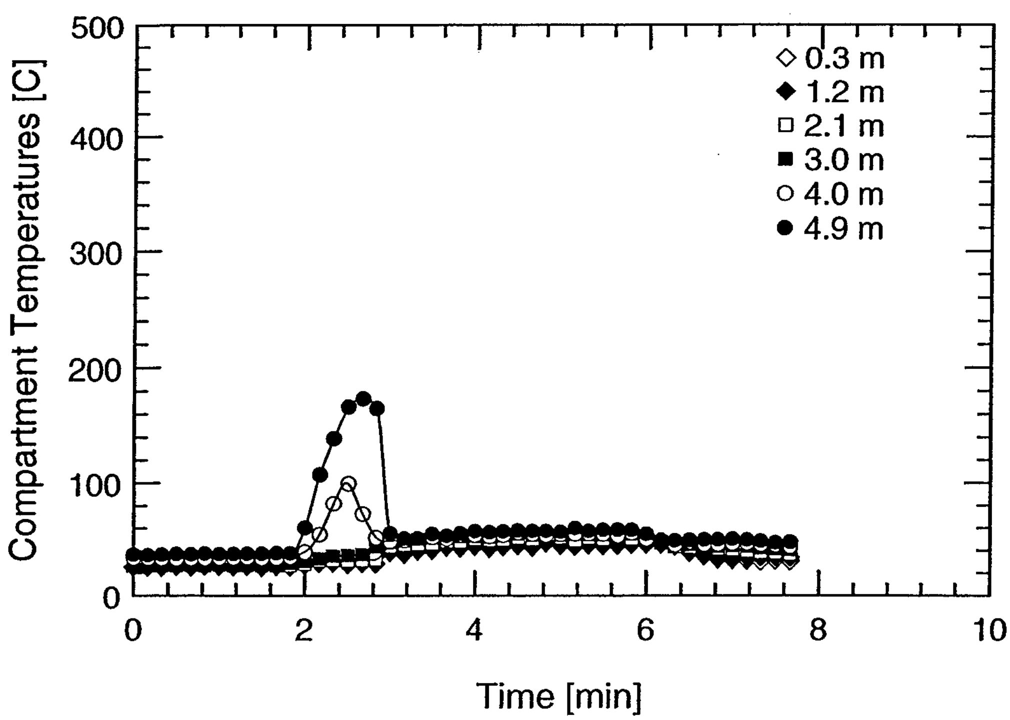


Water Mist System Pressure

Test #5

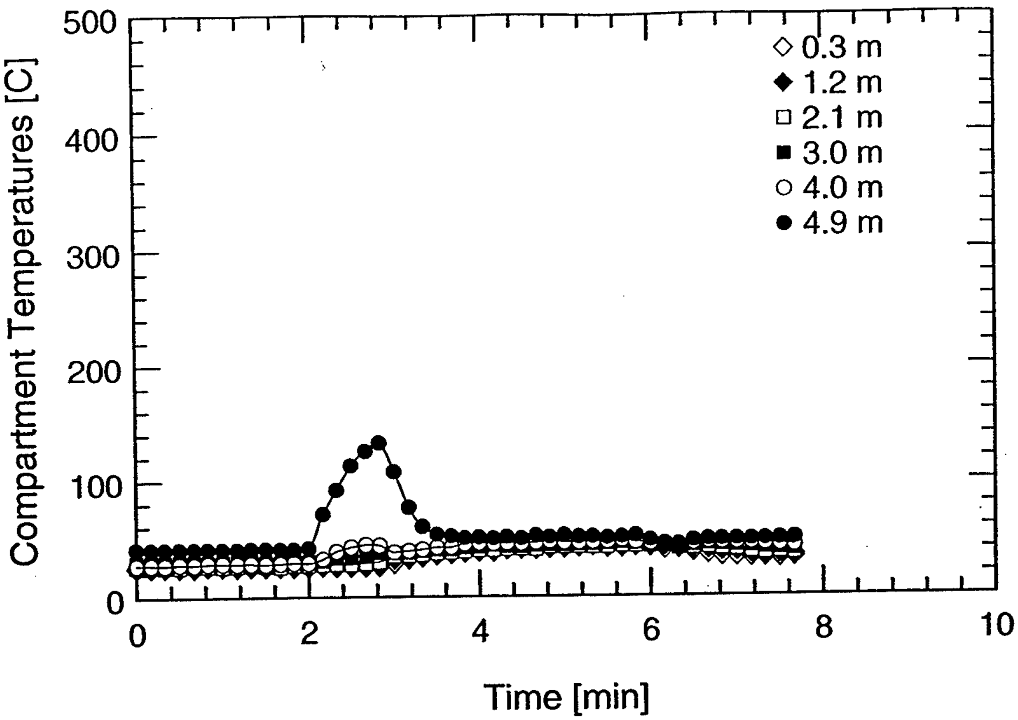


5-22-1

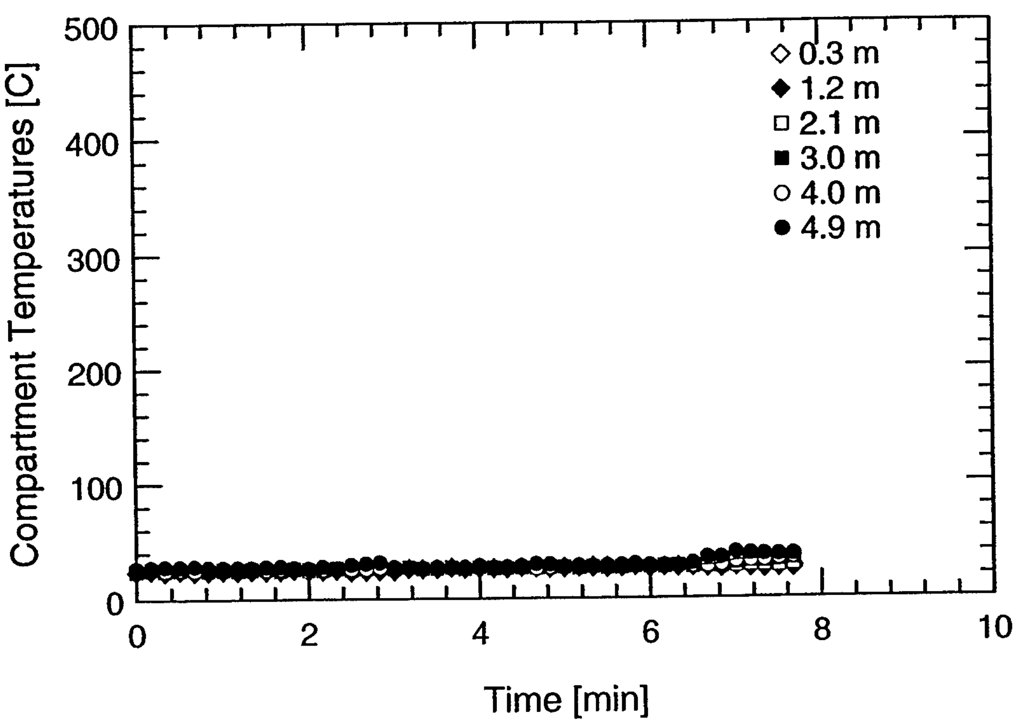


5-27-1

Test #6

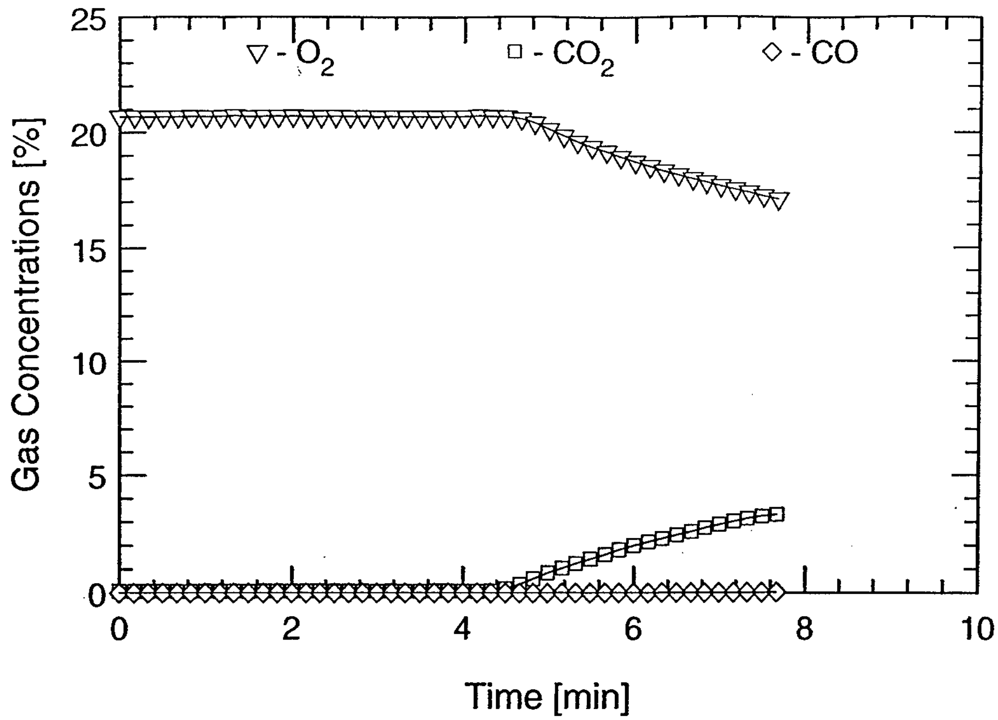


5-27-2

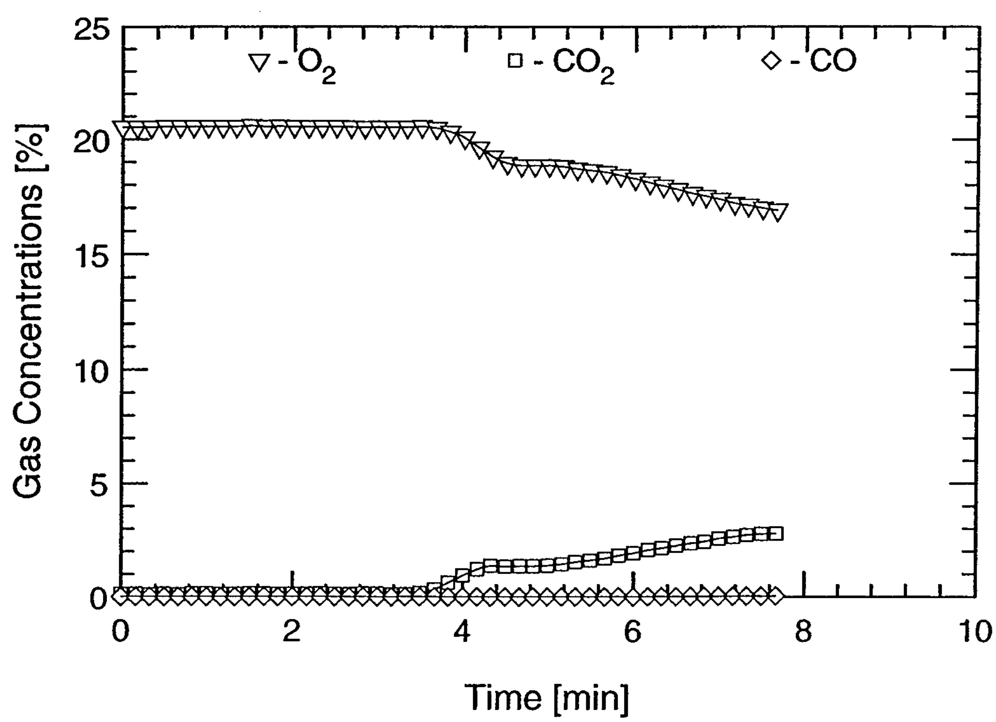


5-35-1

Test #6

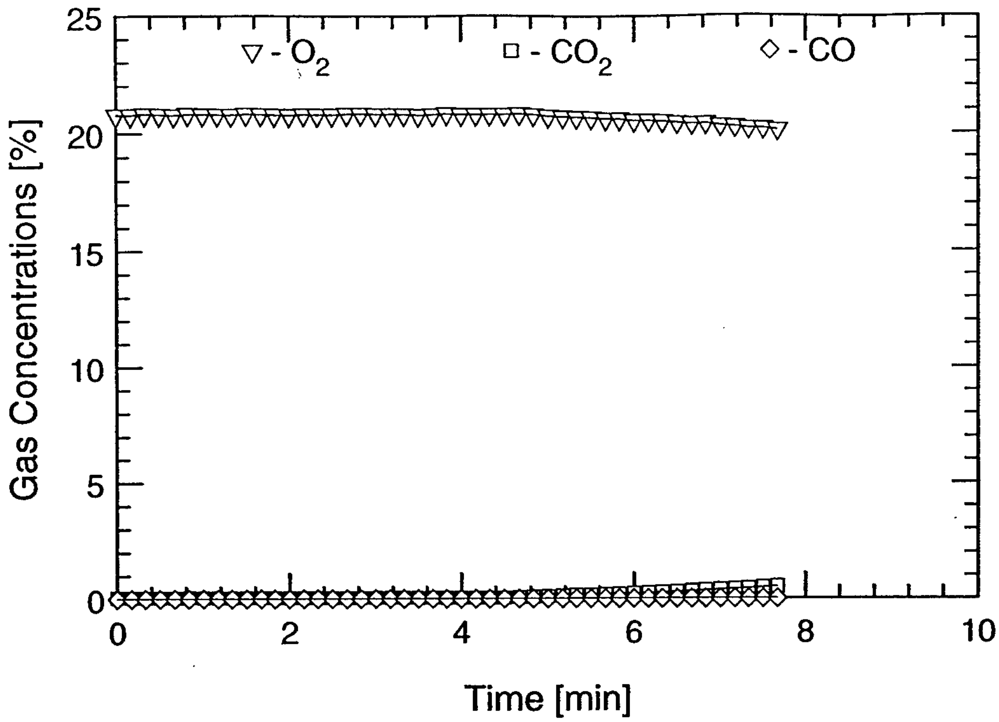


FR 22 - 0.5 m

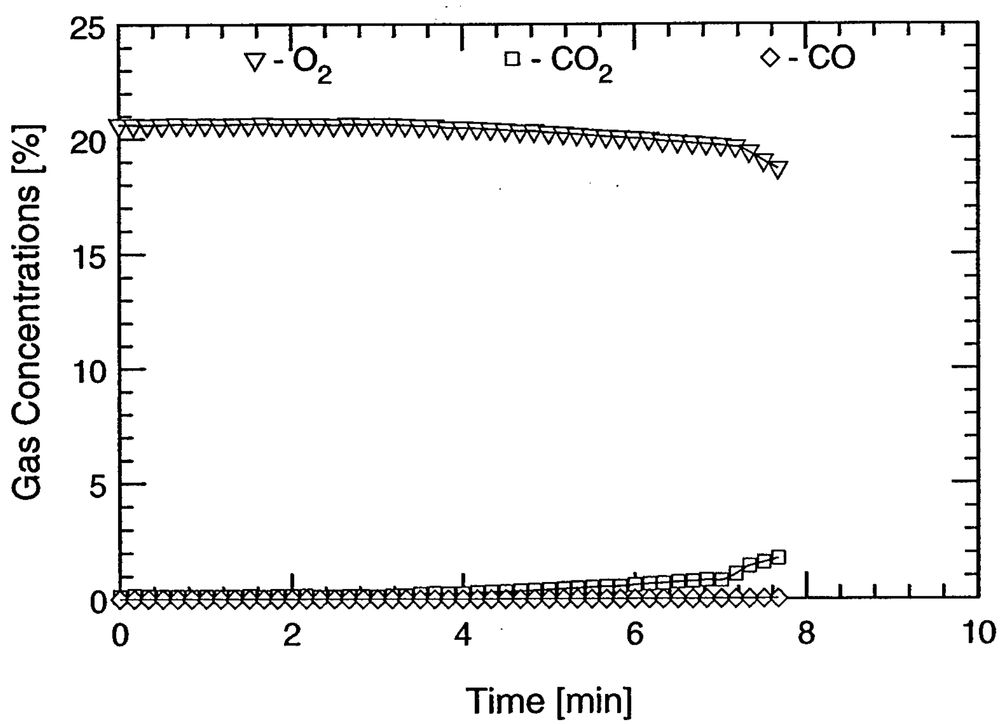


FR 22 - 4.5 m

Test #6

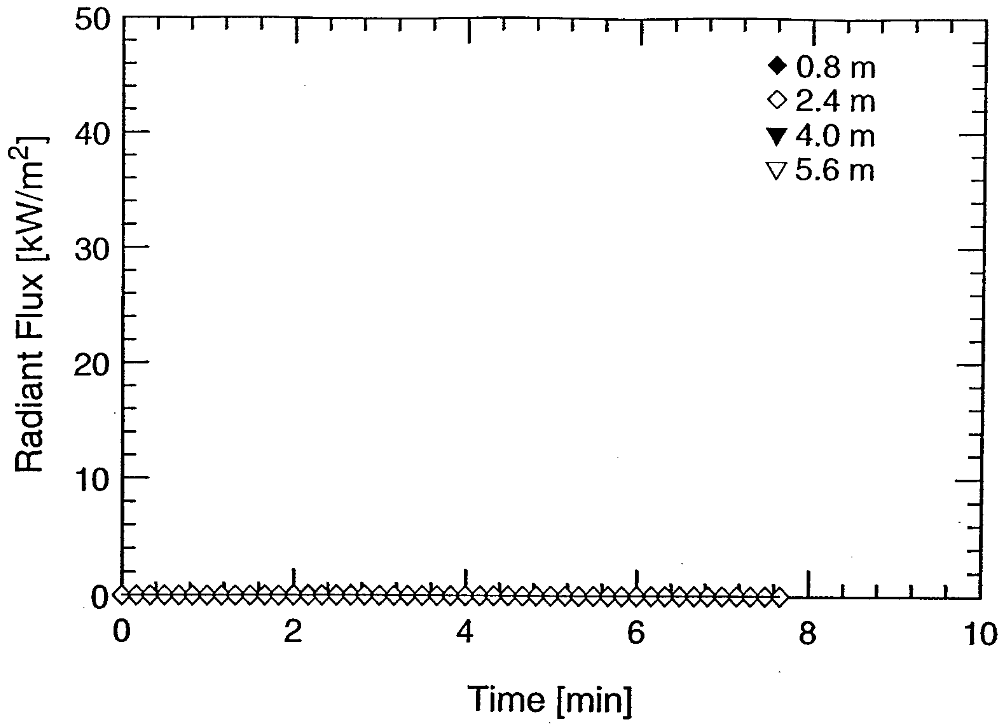


FR 36 - 0.5 m

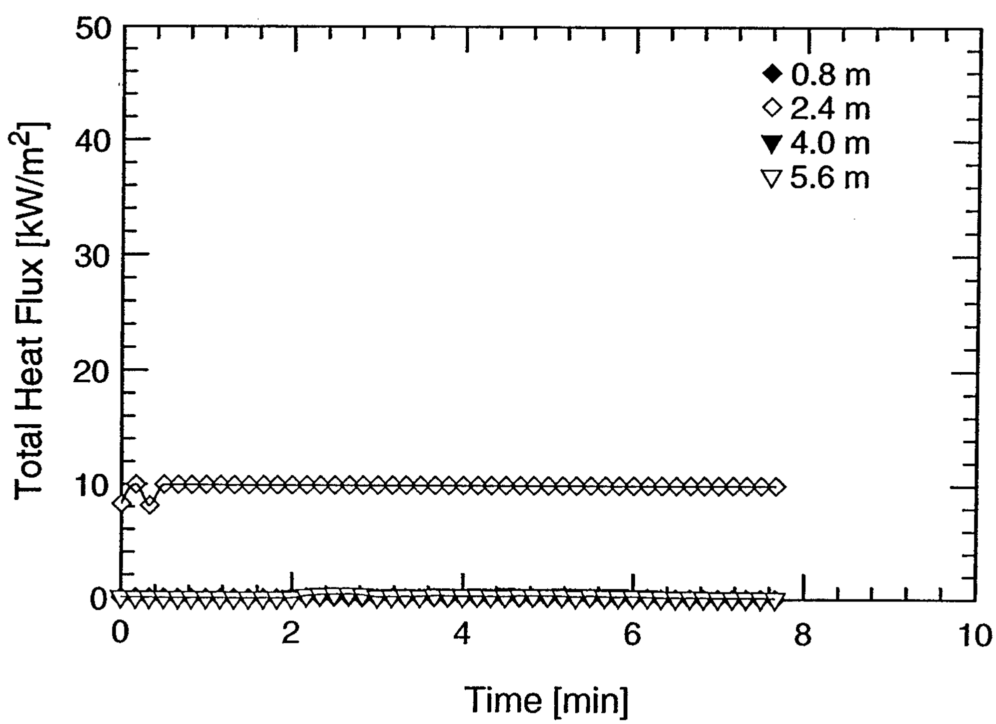


FR 36 - 4.5 m

Test #6

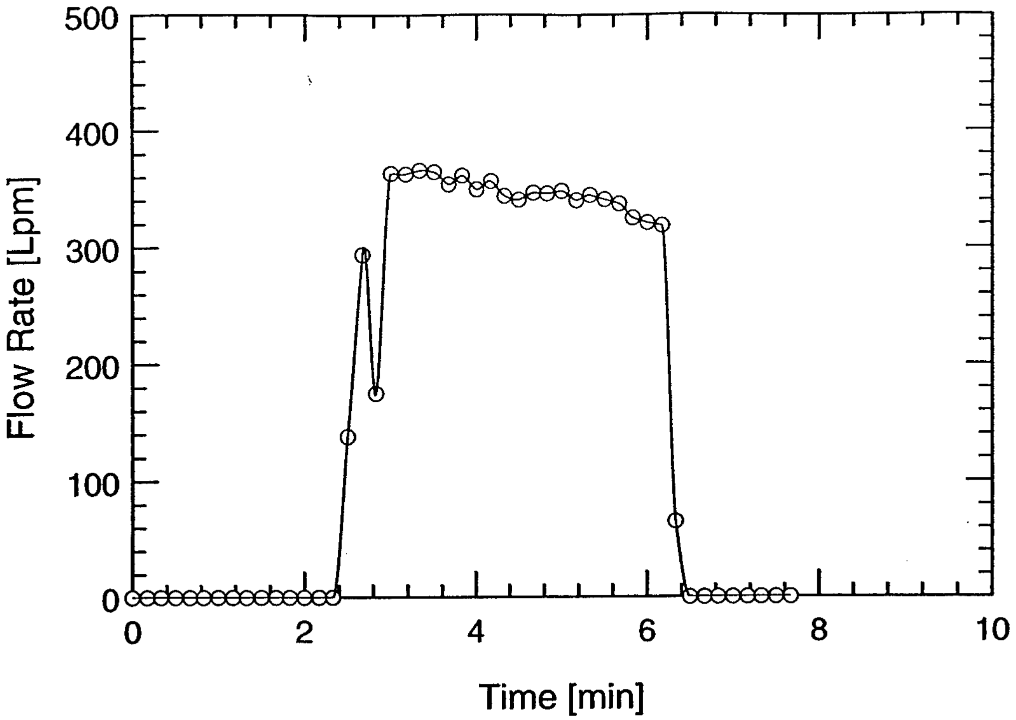


FR 22

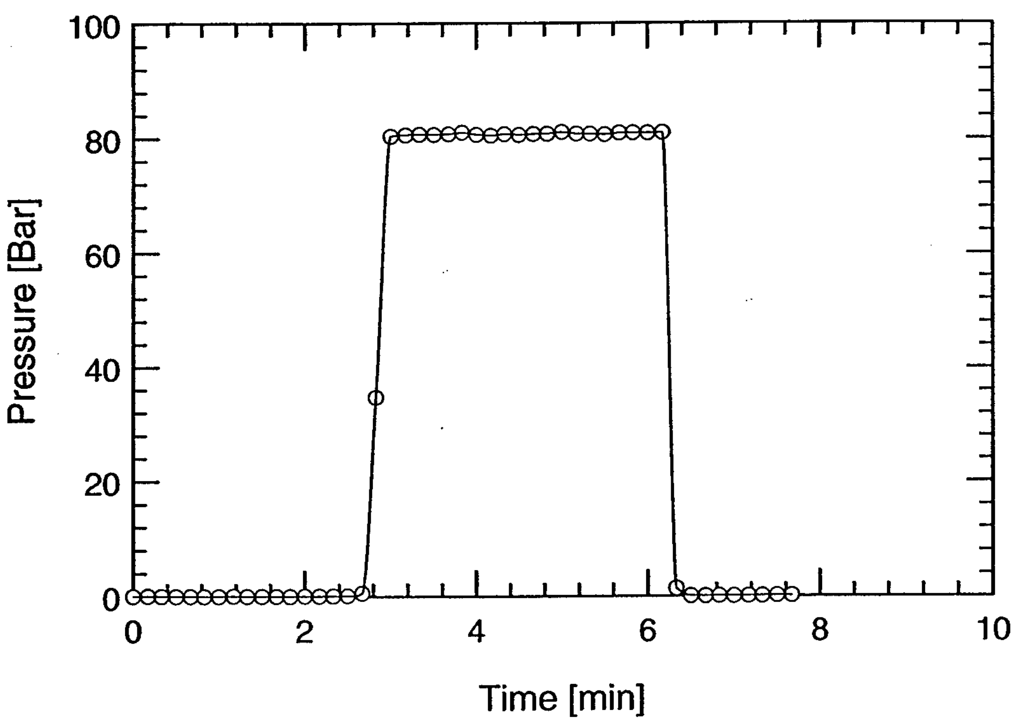


FR 22

Test #6

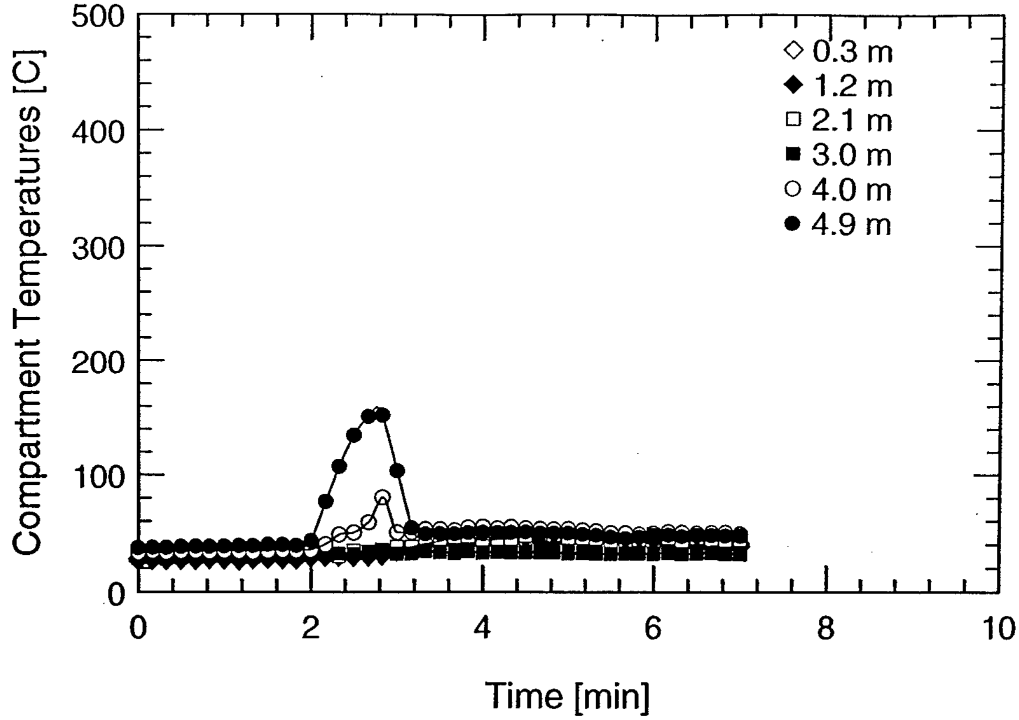


Water Mist System Flow Rate

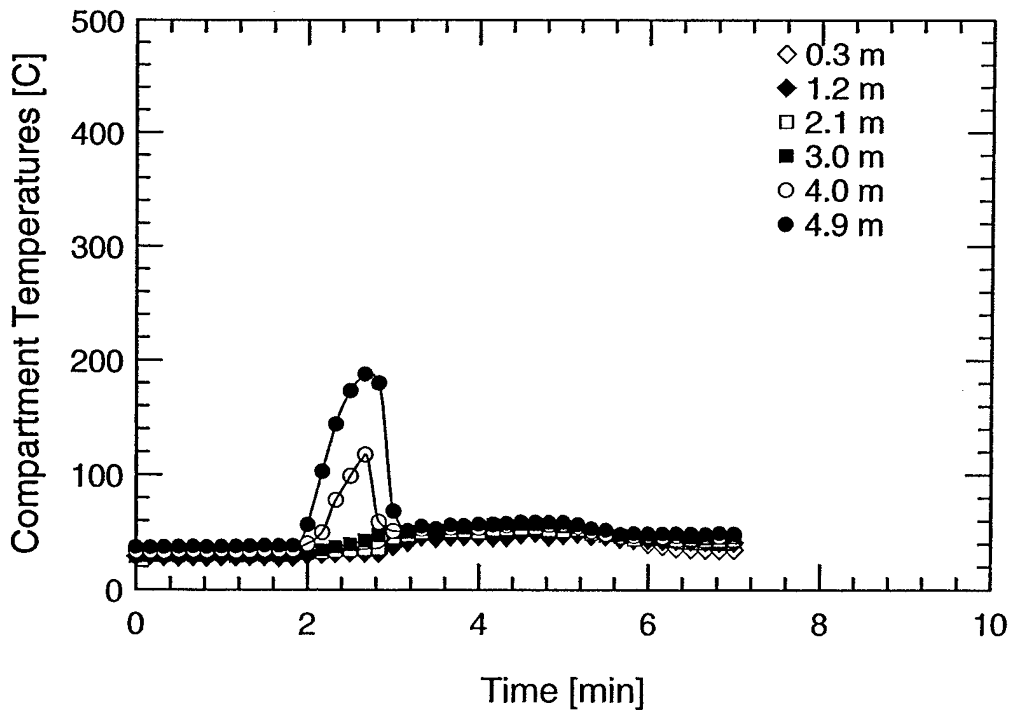


Water Mist System Pressure

Test #6

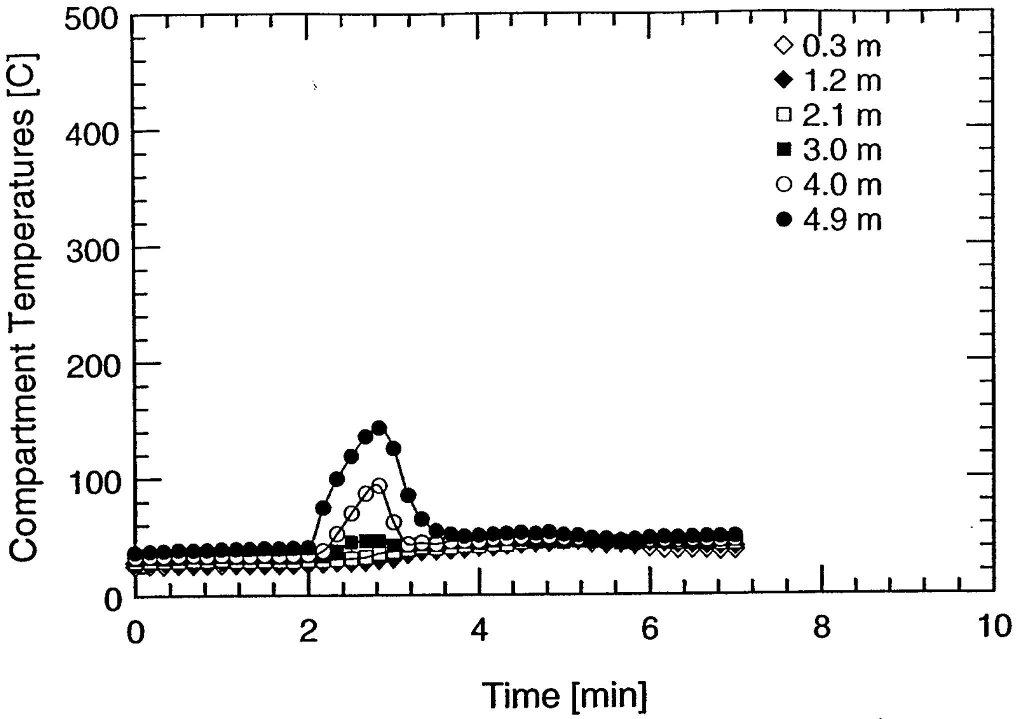


5-22-1

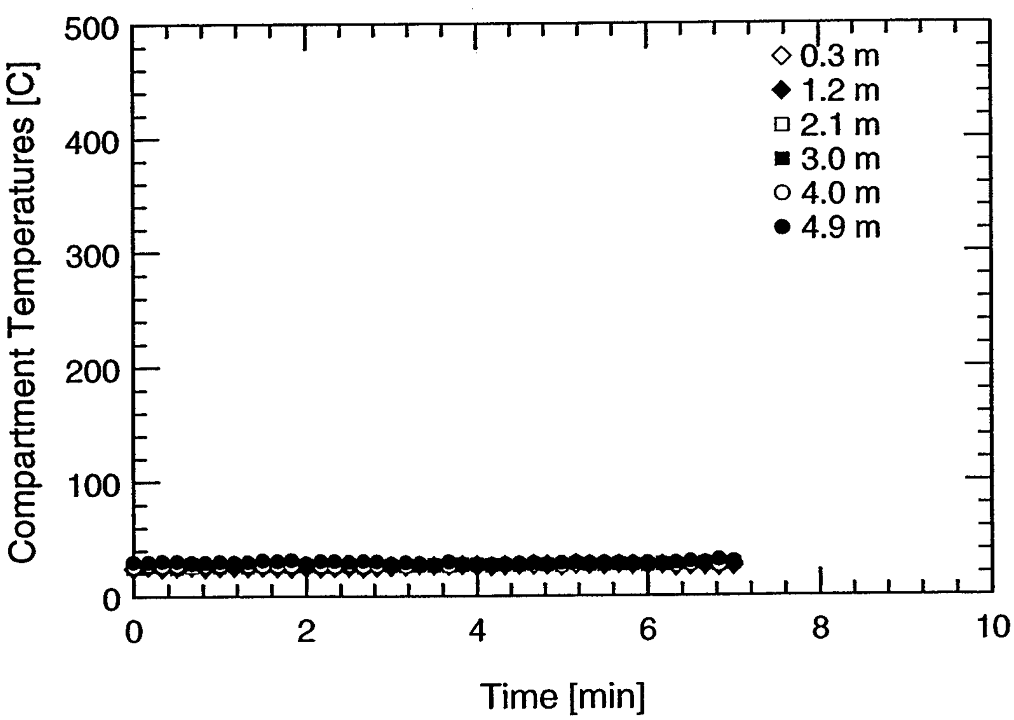


5-27-1

Test #7

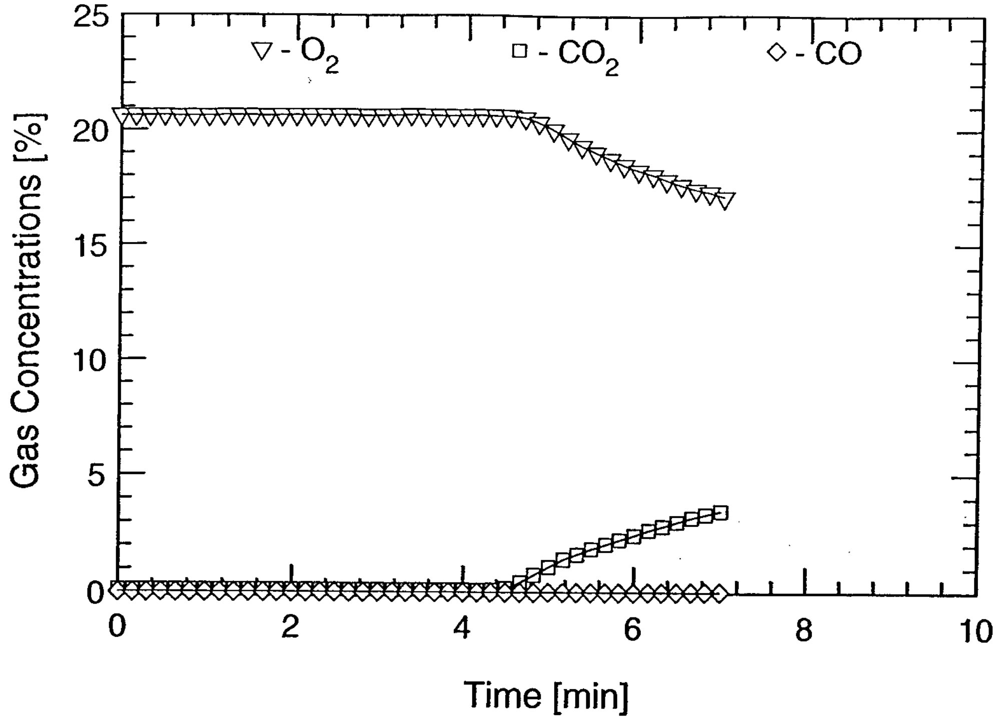


5-27-2

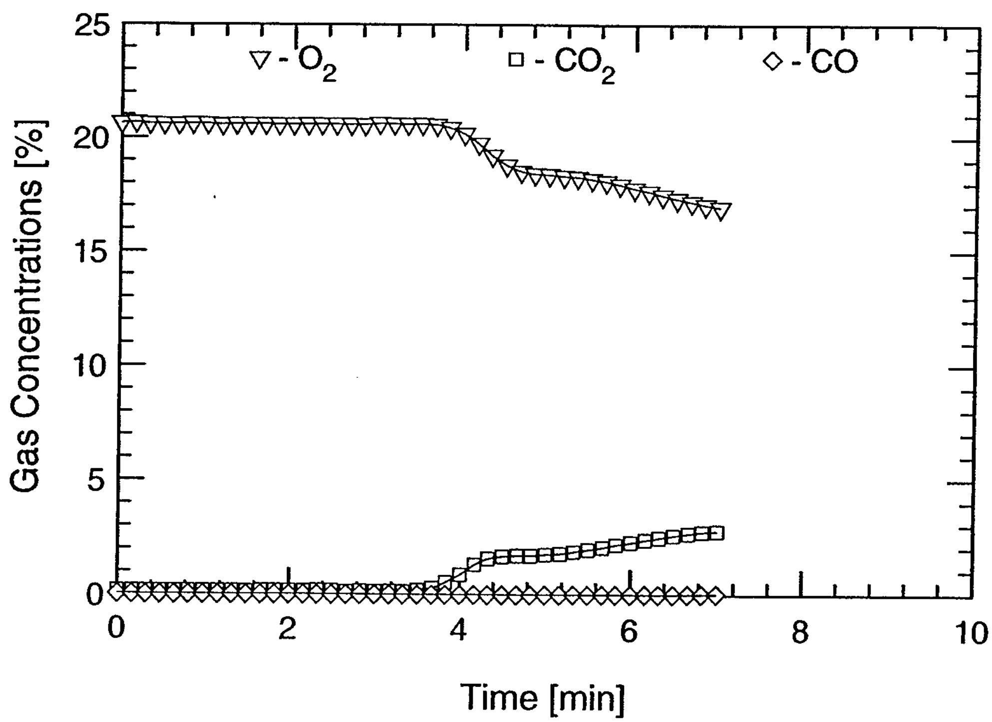


5-35-1

Test #7

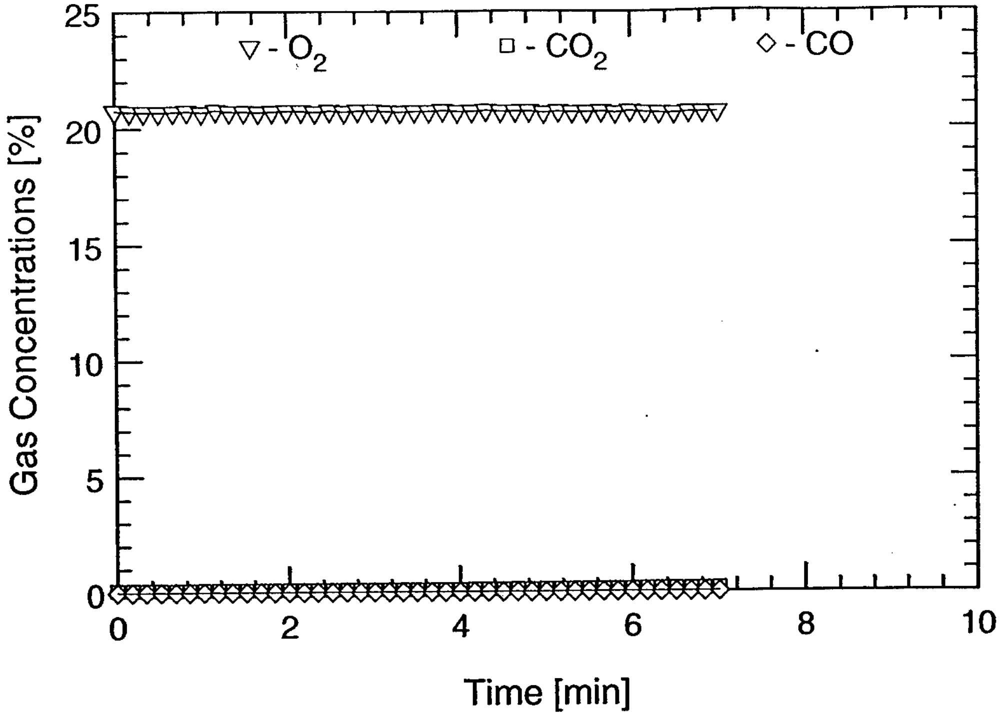


FR 22 - 0.5 m

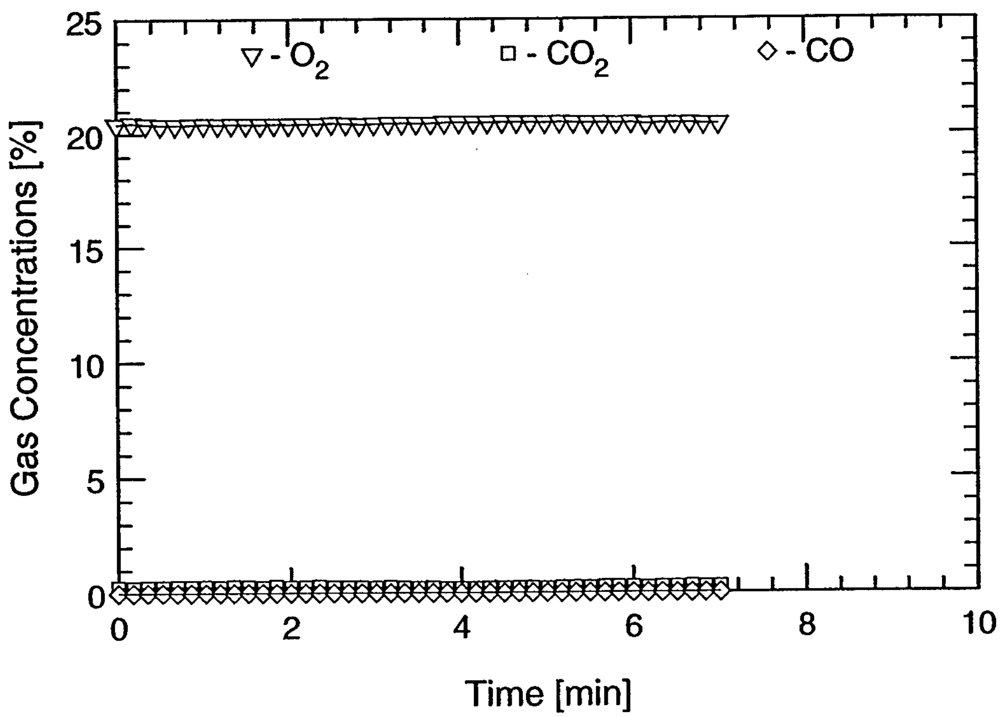


FR 22 - 4.5 m

Test #7

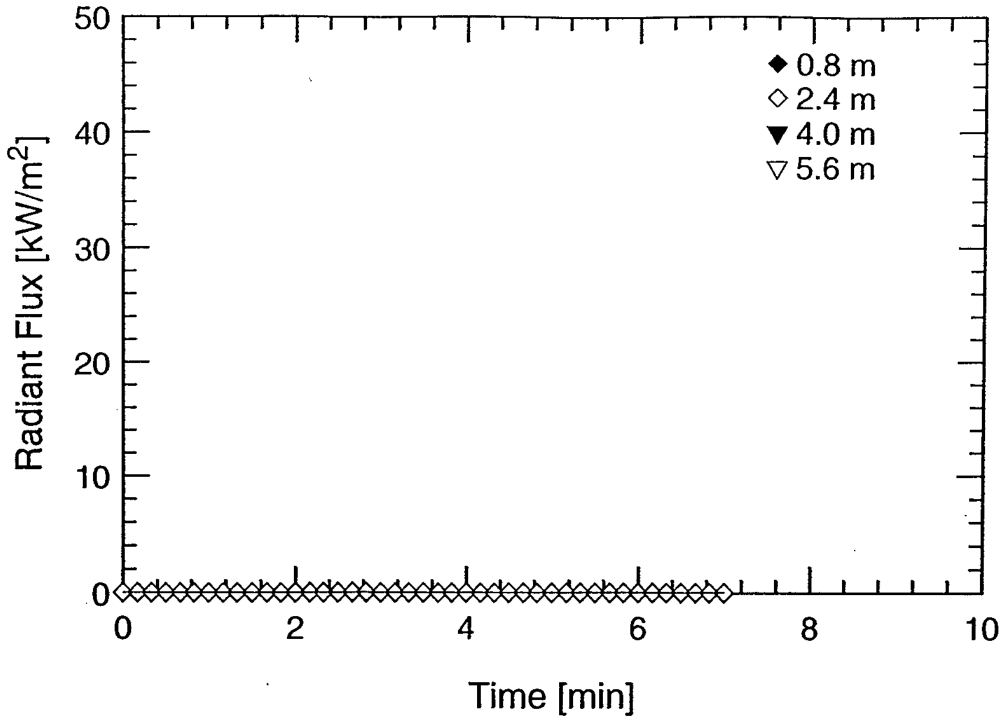


FR 36 - 0.5 m

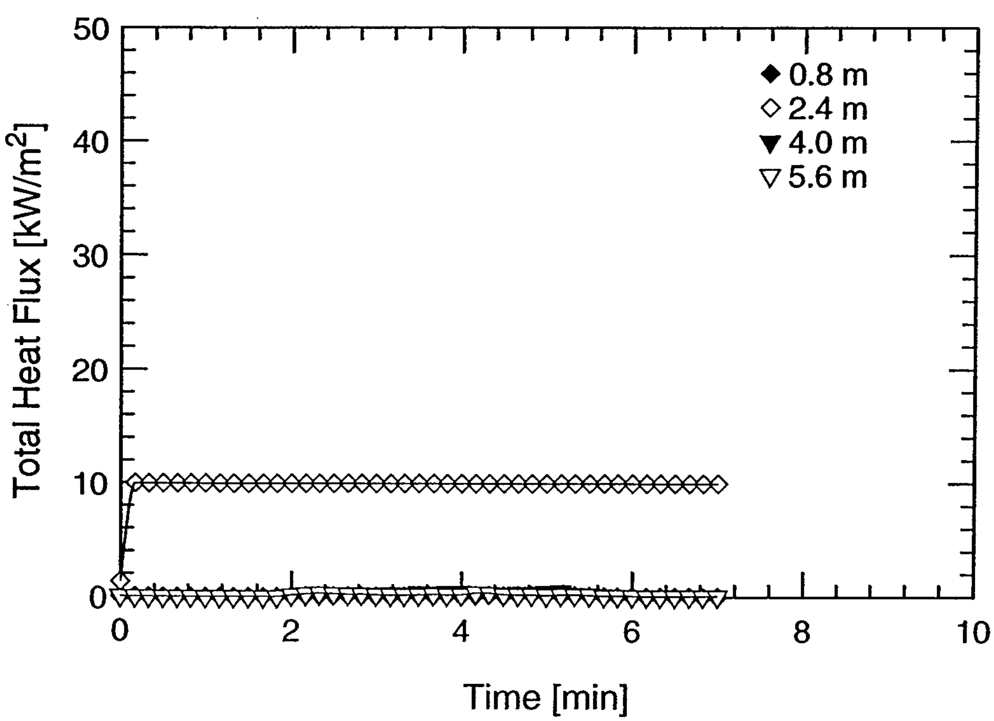


FR 36 - 4.5 m

Test #7

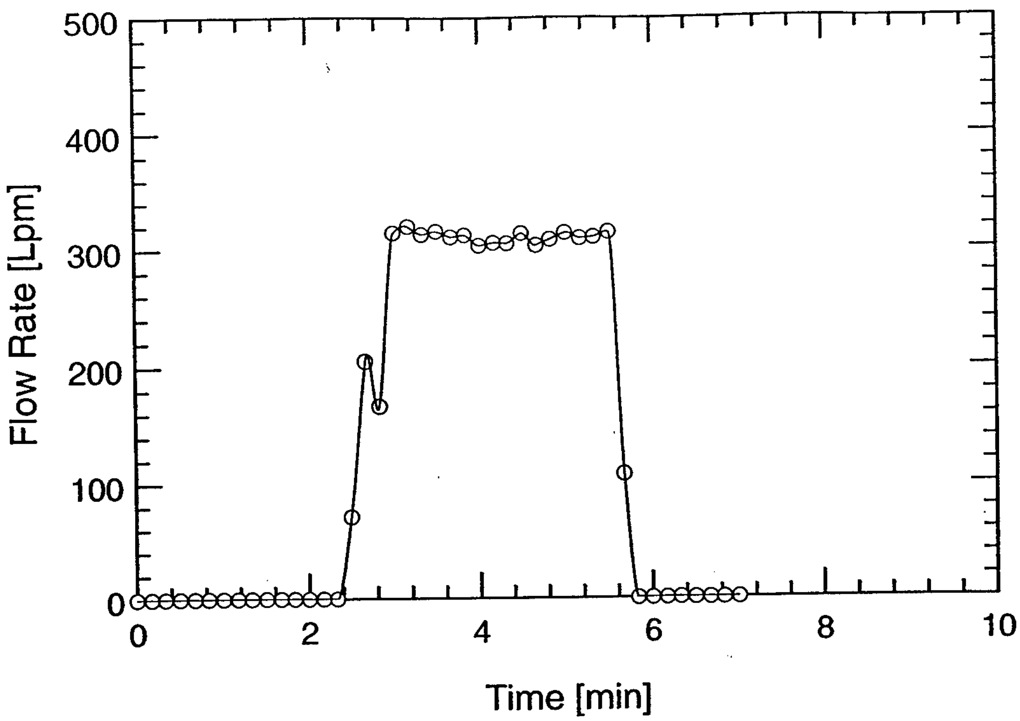


FR 22

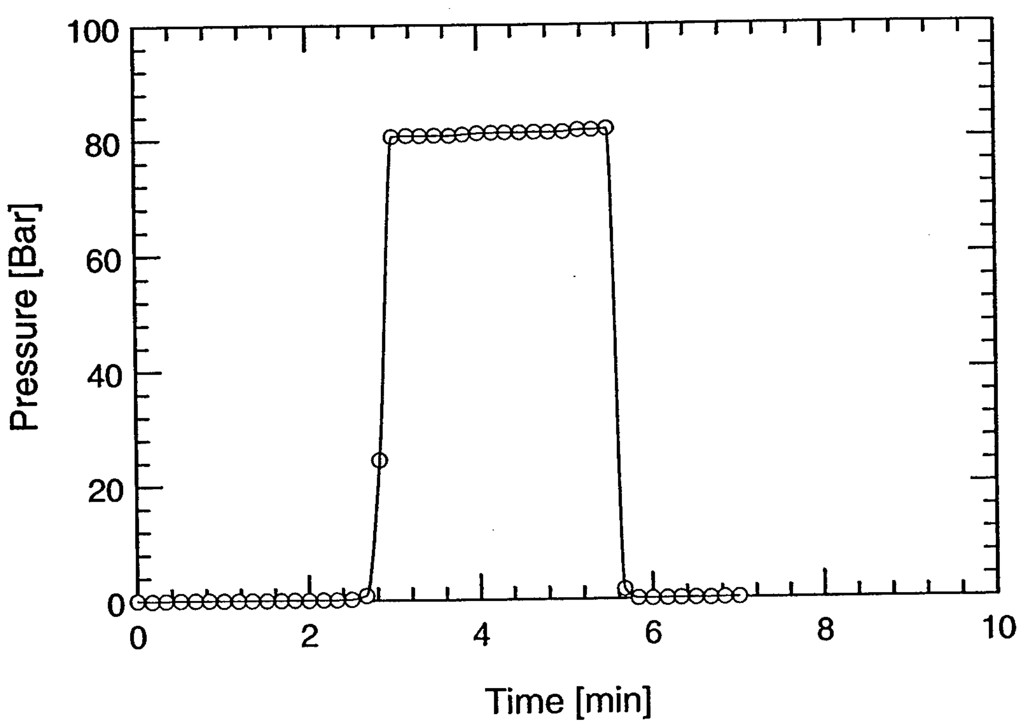


FR 22

Test #7

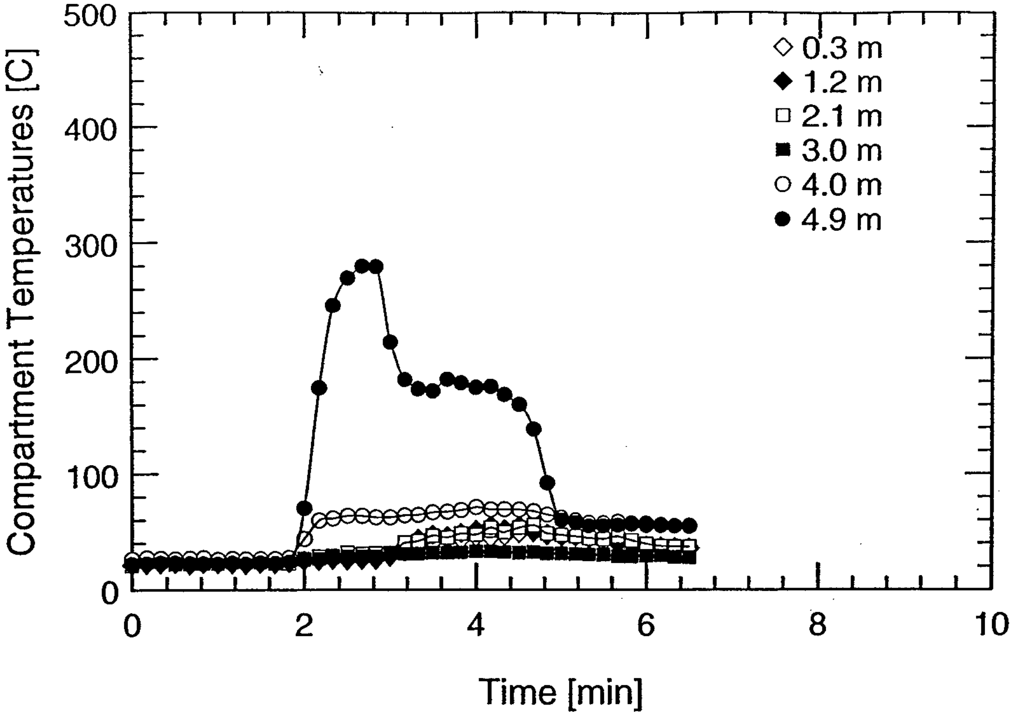


Water Mist System Flow Rate

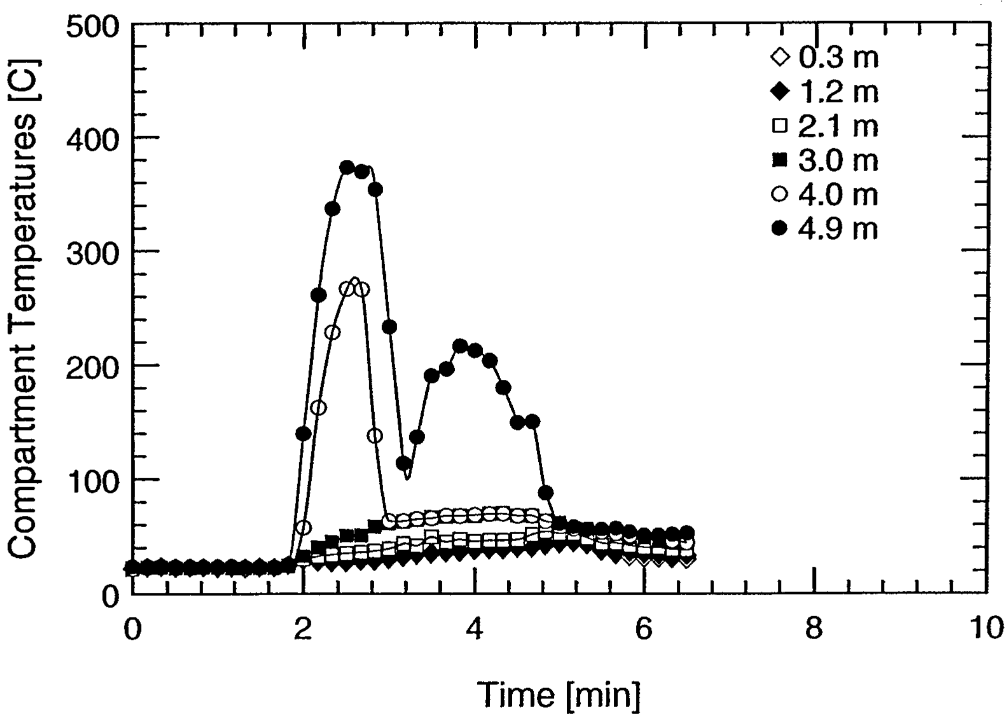


Water Mist System Pressure

Test #7

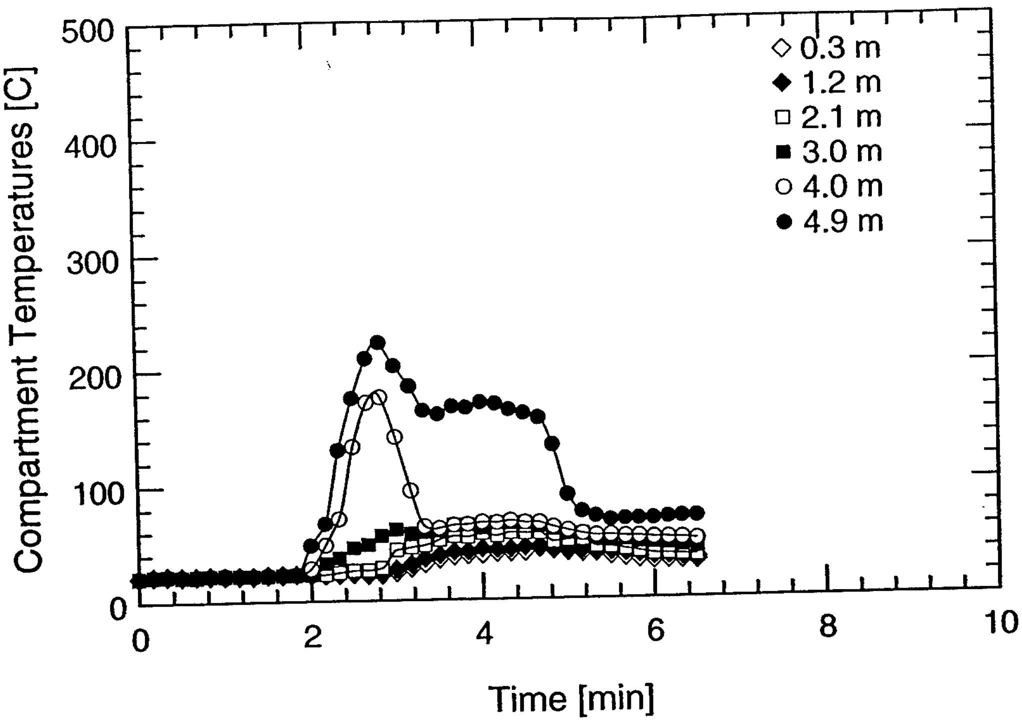


5-22-1

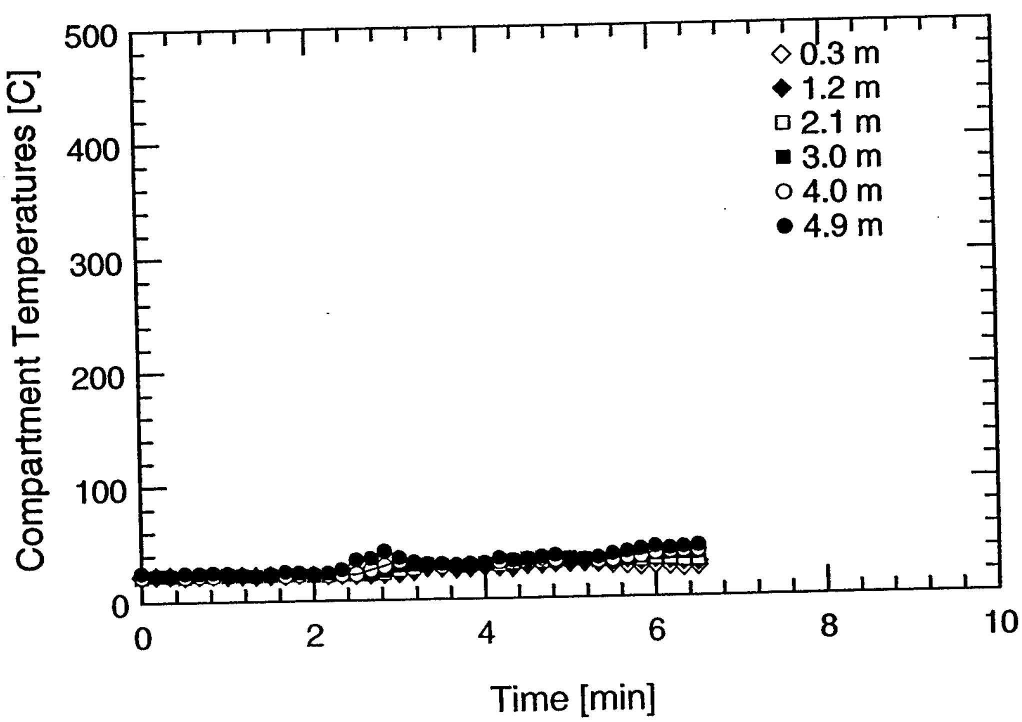


5-27-1

Test #8

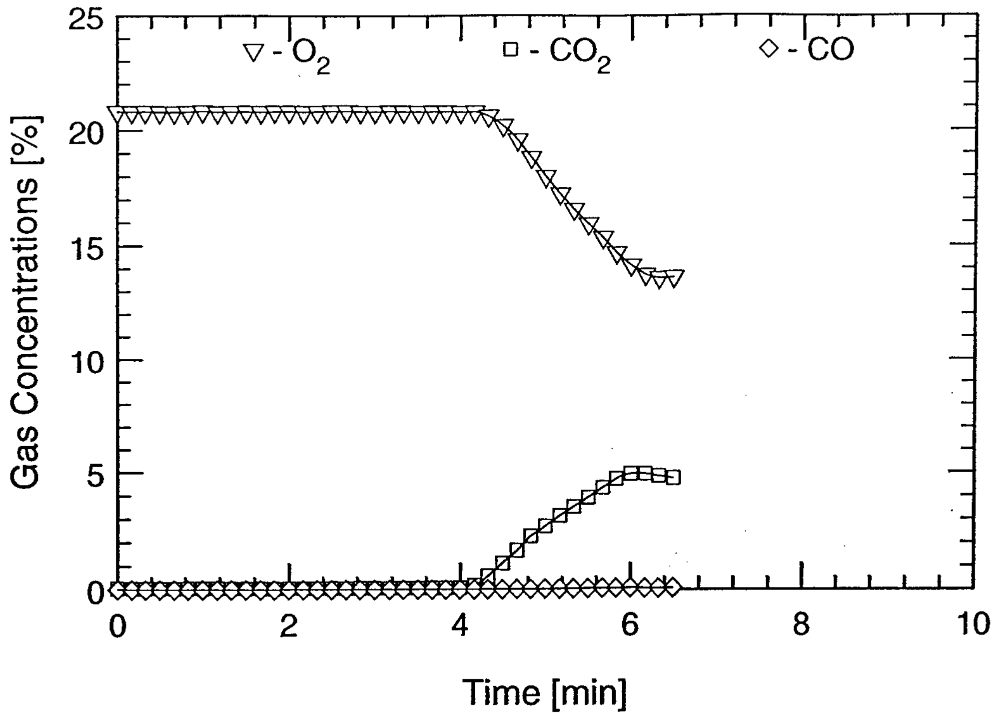


5-27-2

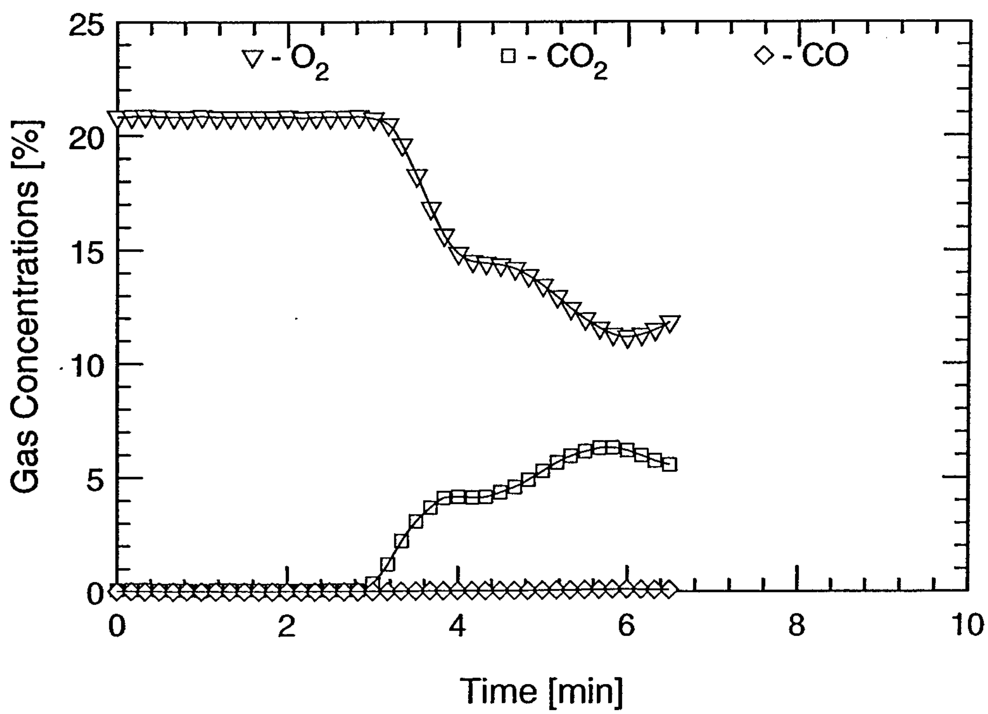


5-35-1

Test #8

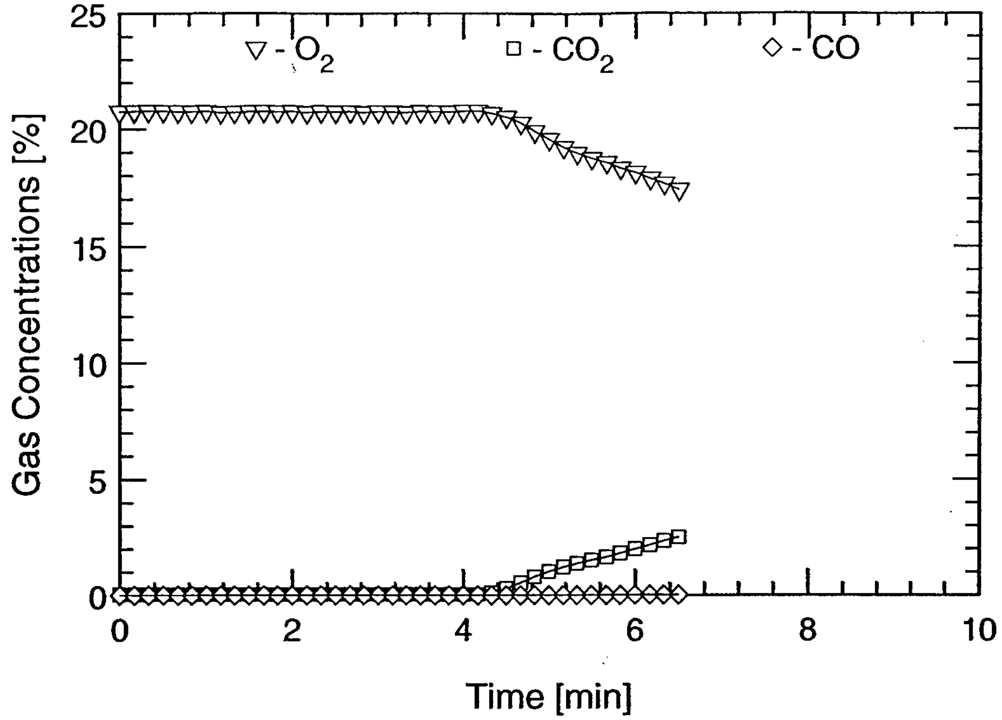


FR 22 - 0.5 m

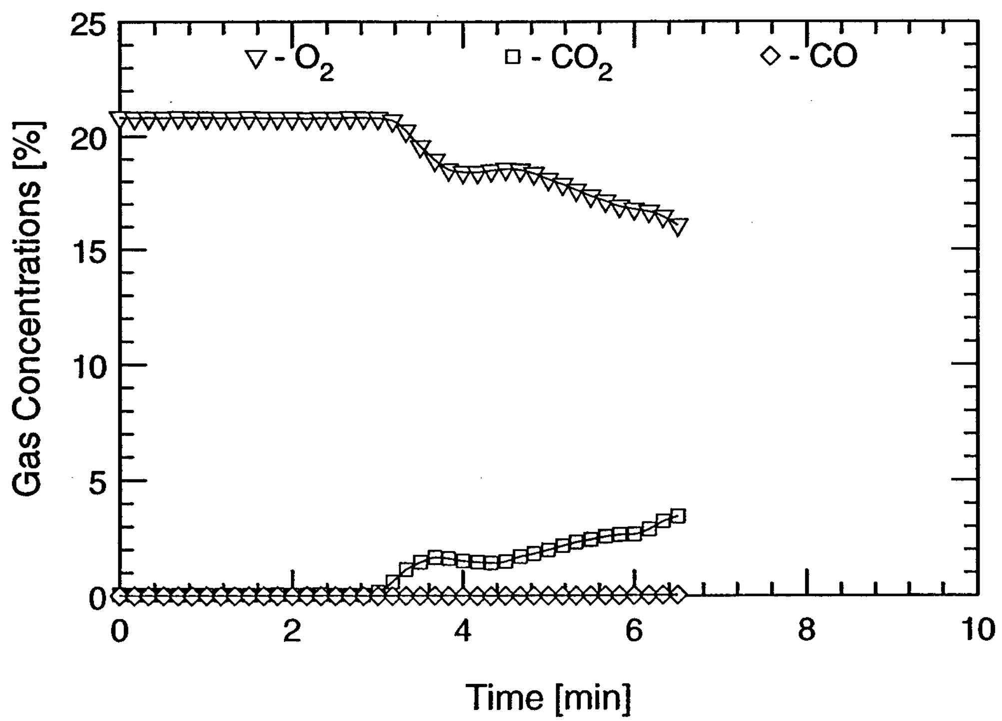


FR 22 - 4.5 m

Test #8

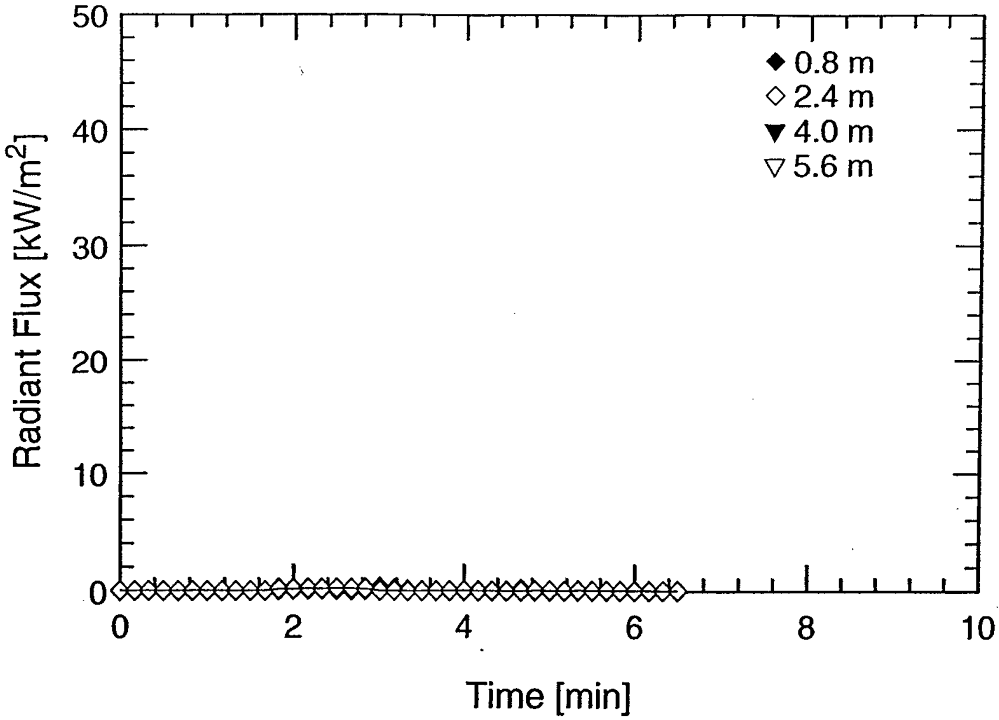


FR 36 - 0.5 m

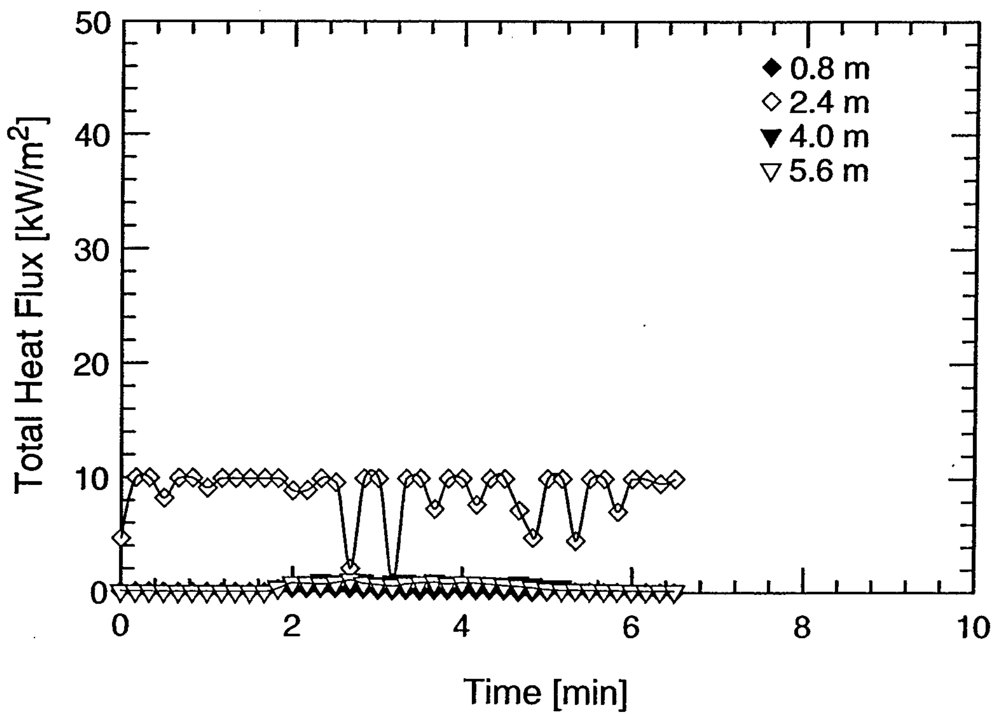


FR 36 - 4.5 m

Test #8

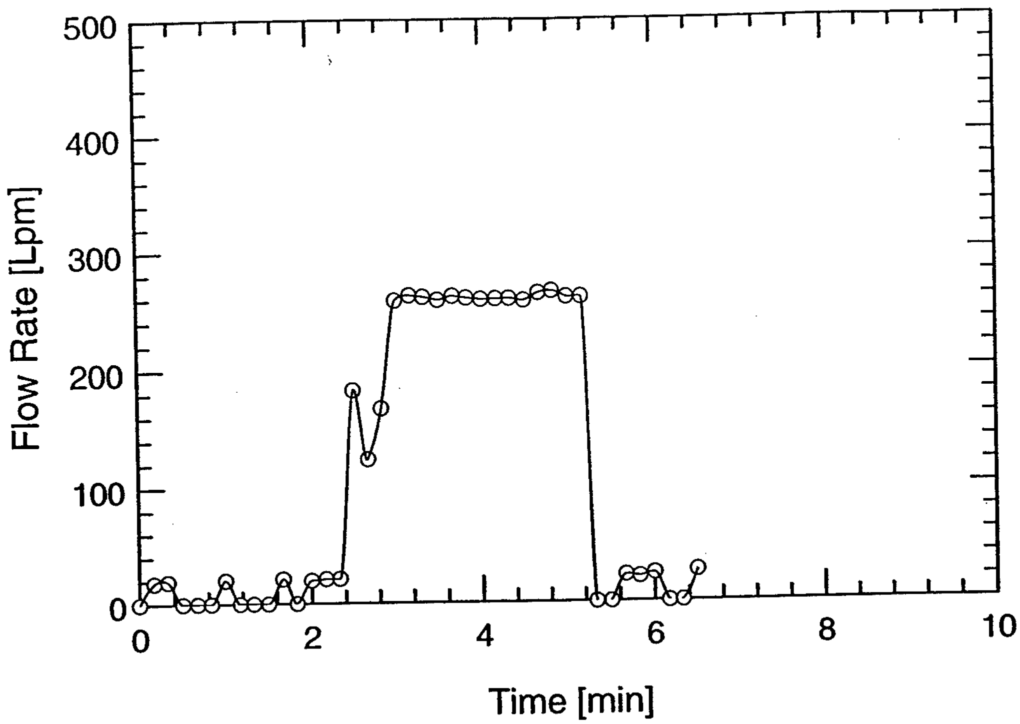


FR 22

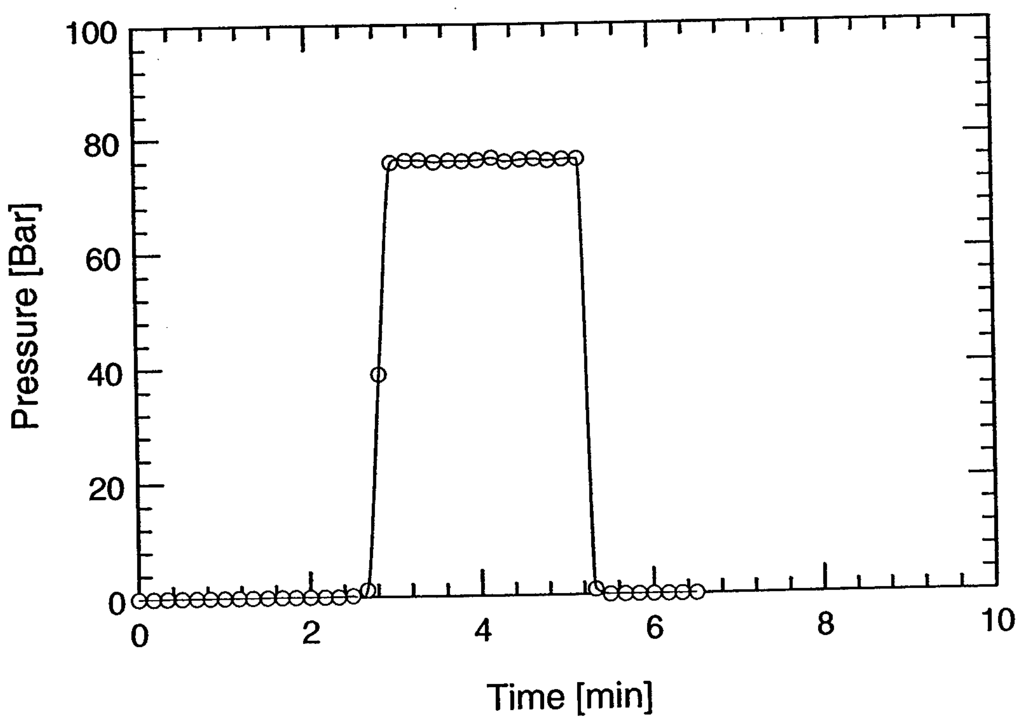


FR 22

Test #8

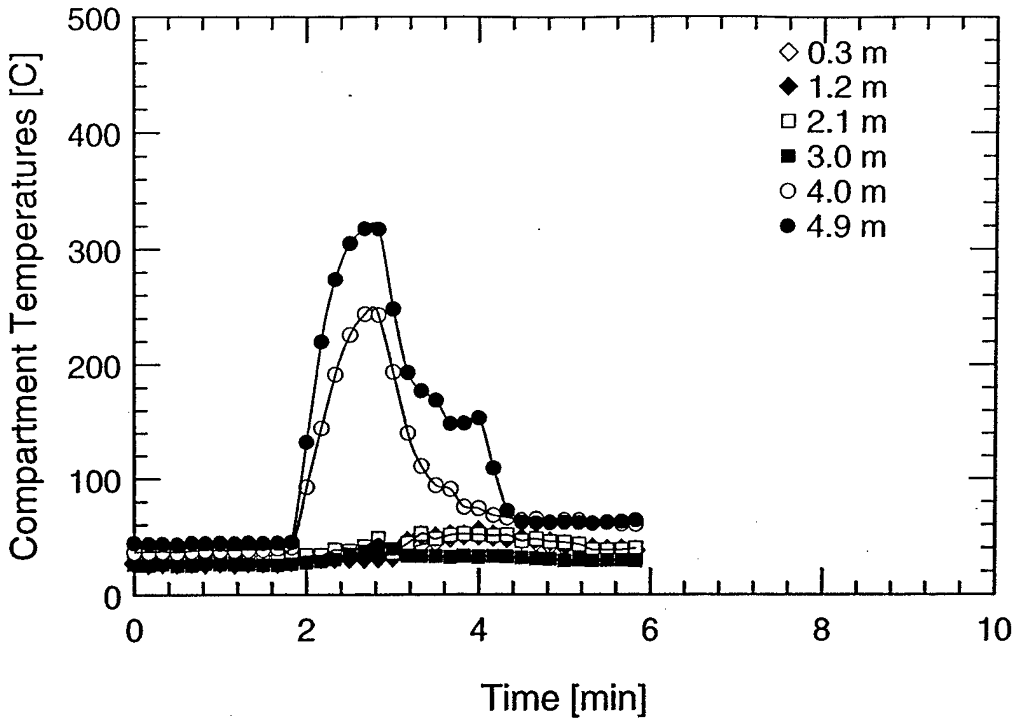


Water Mist System Flow Rate

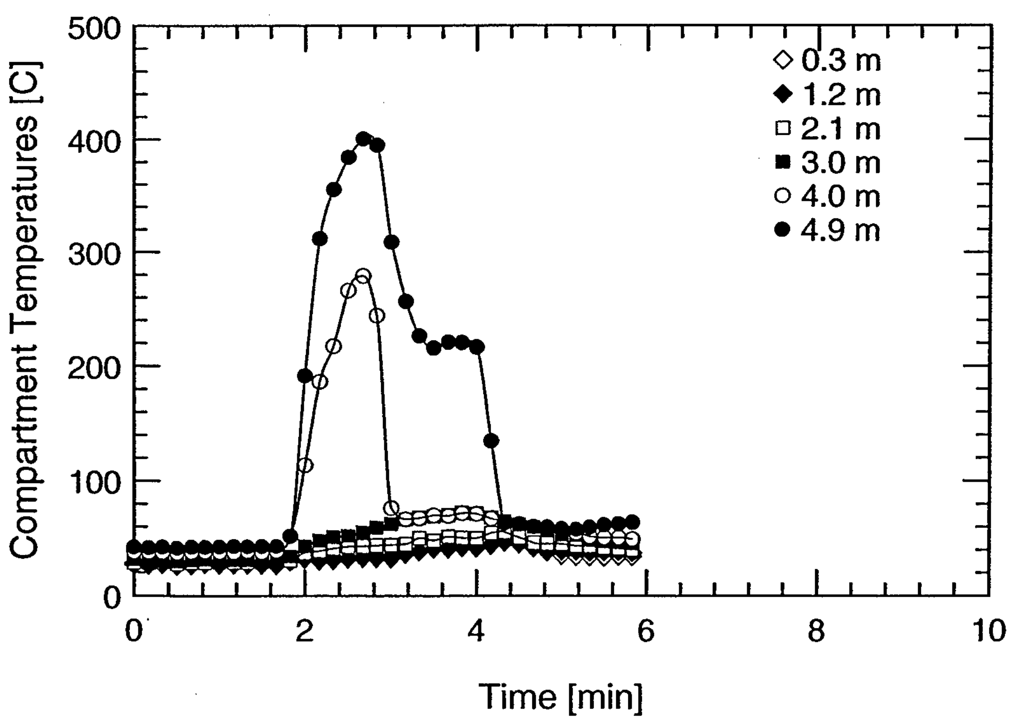


Water Mist System Pressure

Test #8

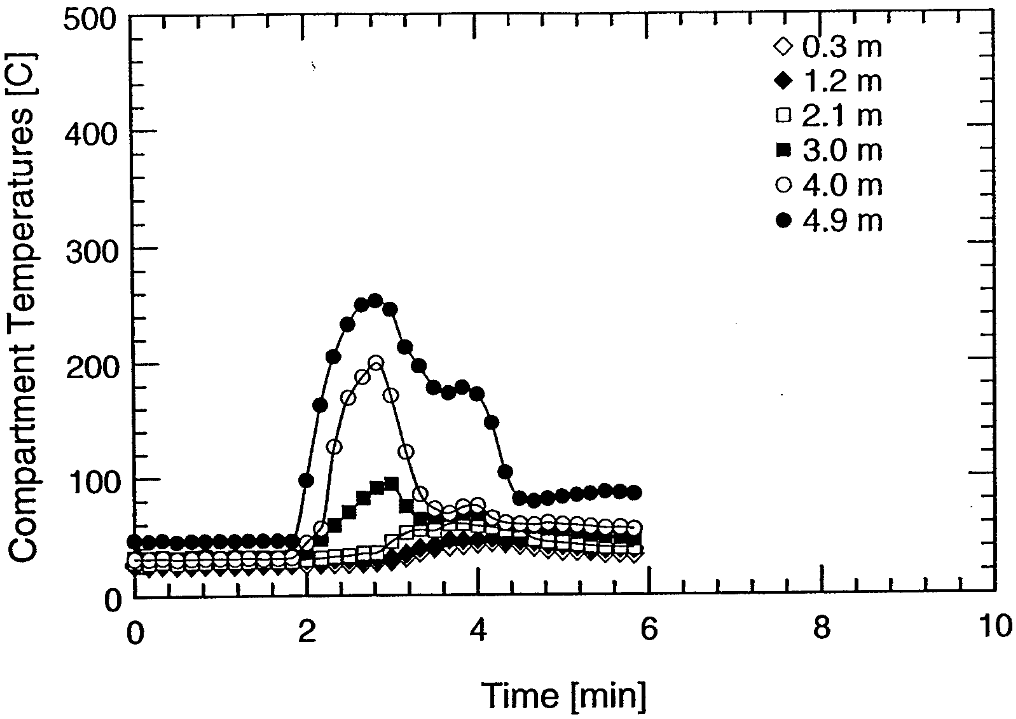


5-22-1

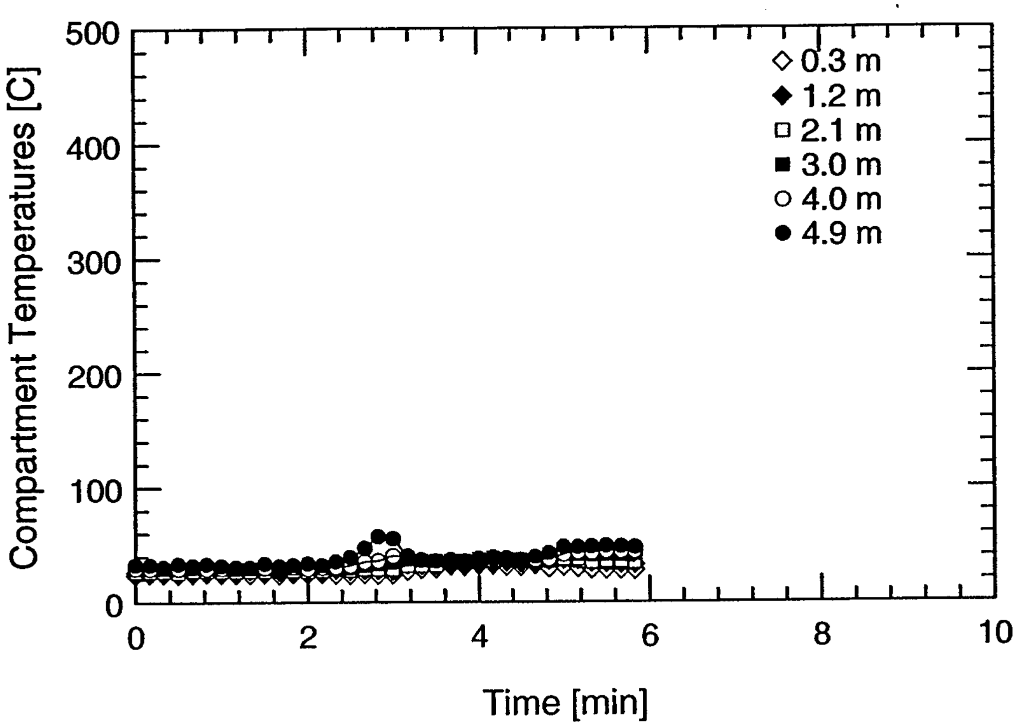


5-27-1

Test #9

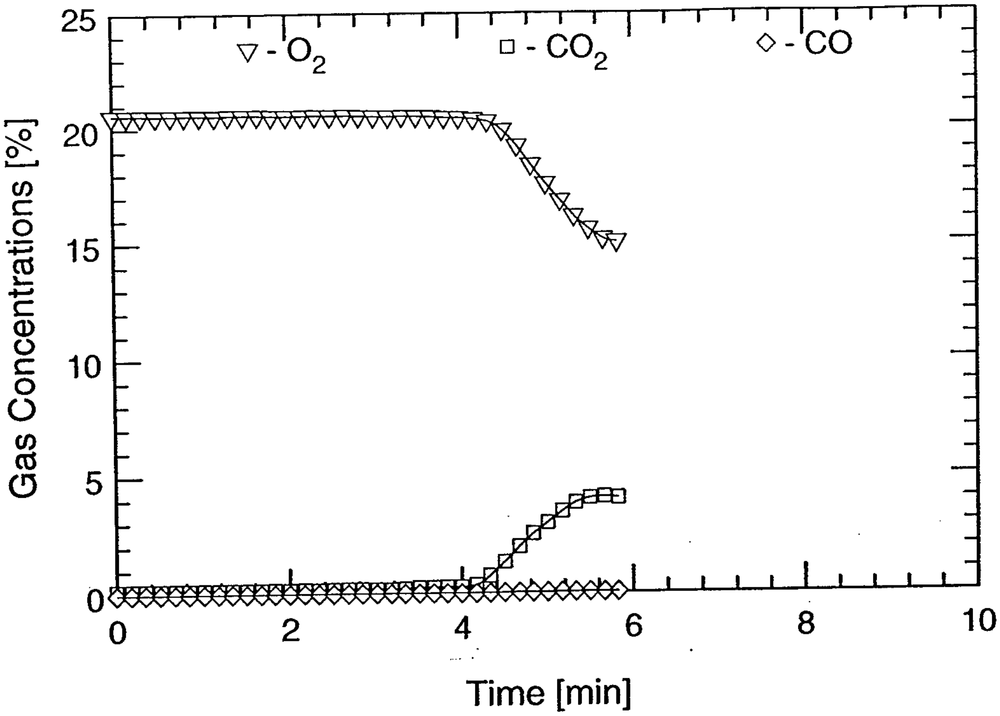


5-27-2

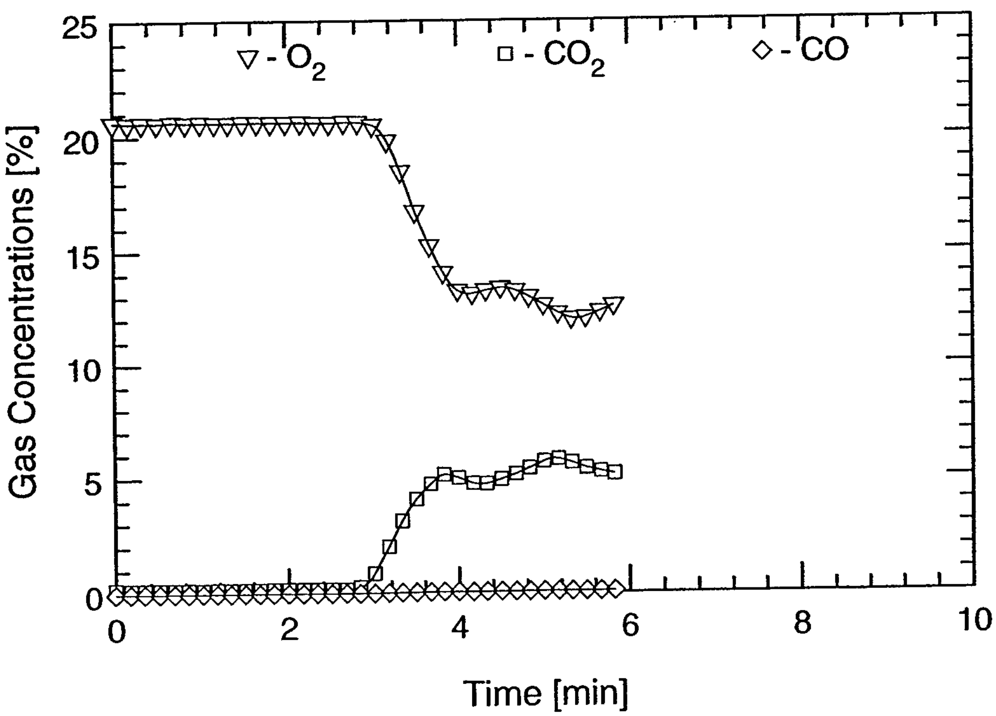


5-35-1

Test #9

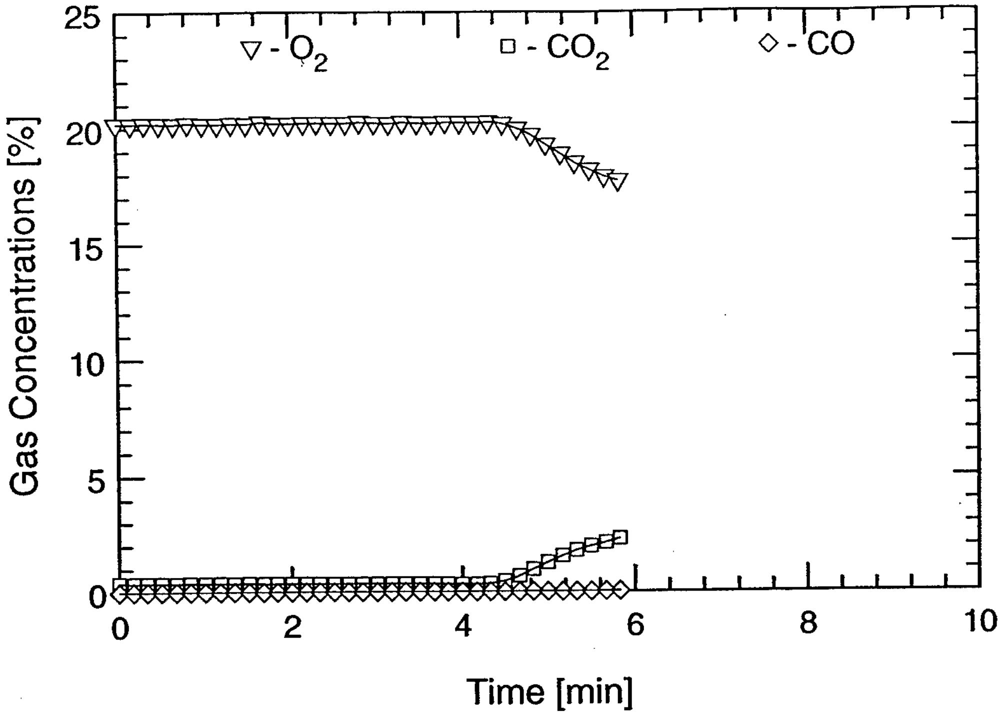


FR 22 - 0.5 m

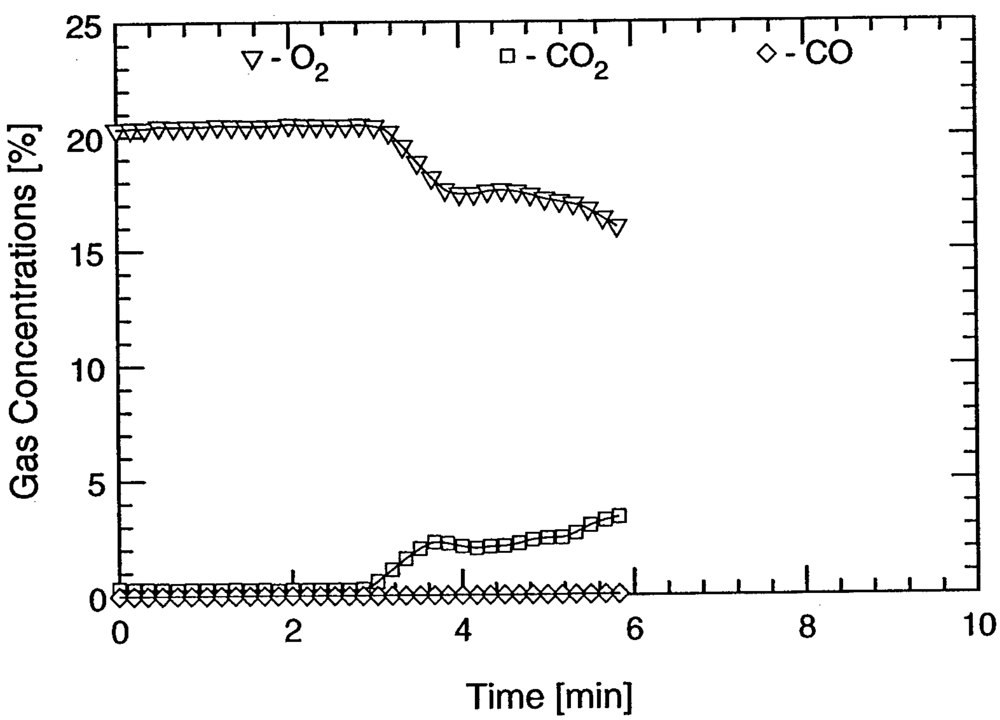


FR 22 - 4.5 m

Test #9

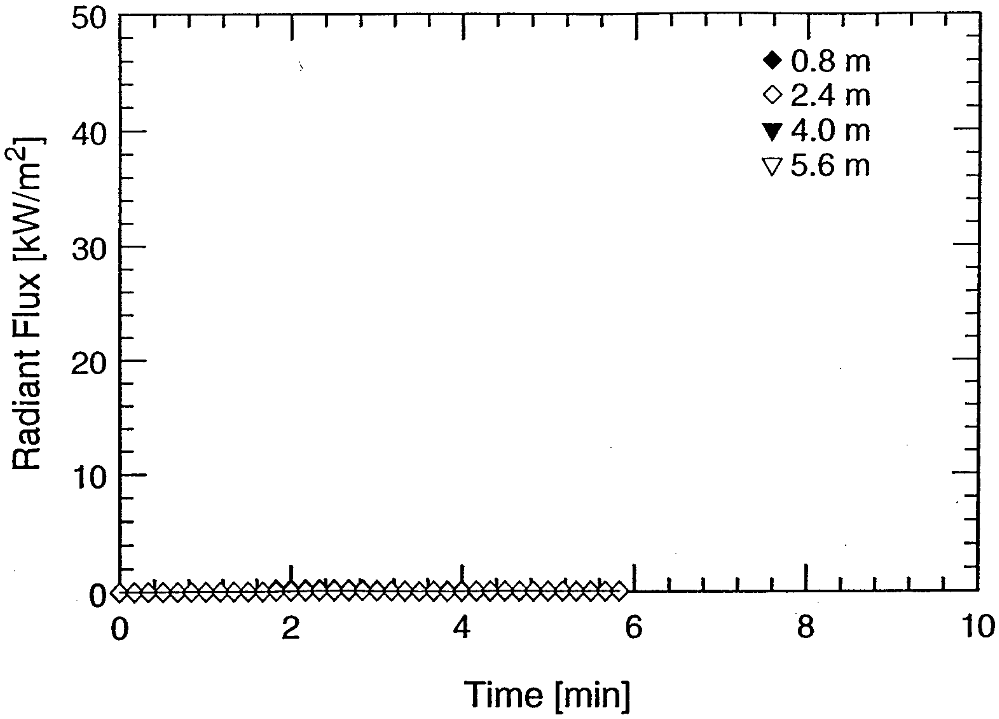


FR 36 - 0.5 m

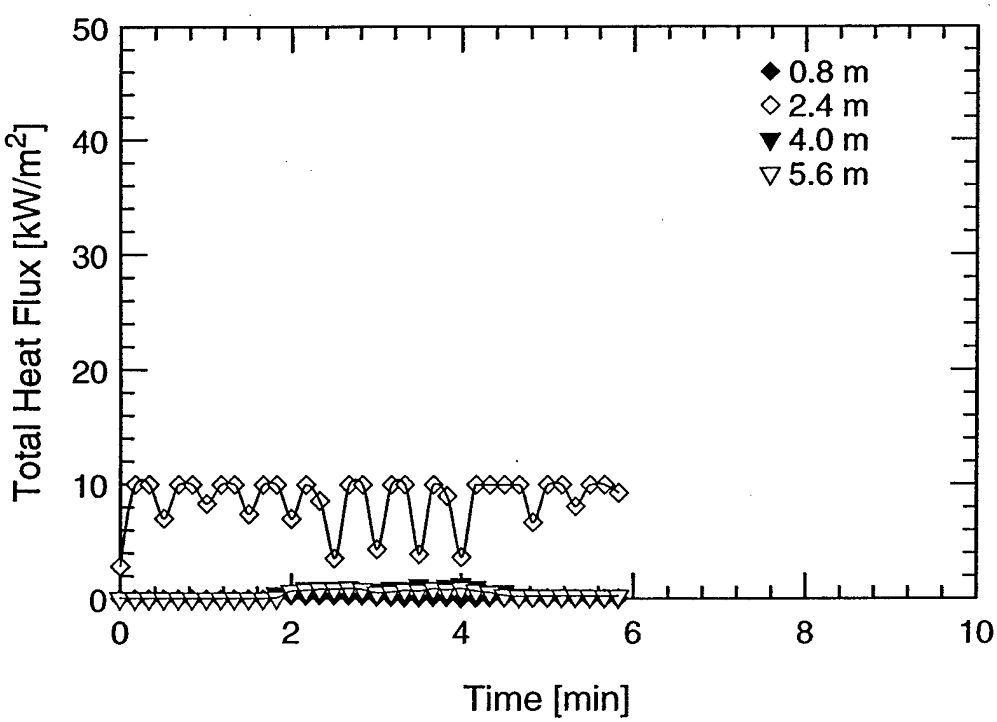


FR 36 - 4.5 m

Test #9

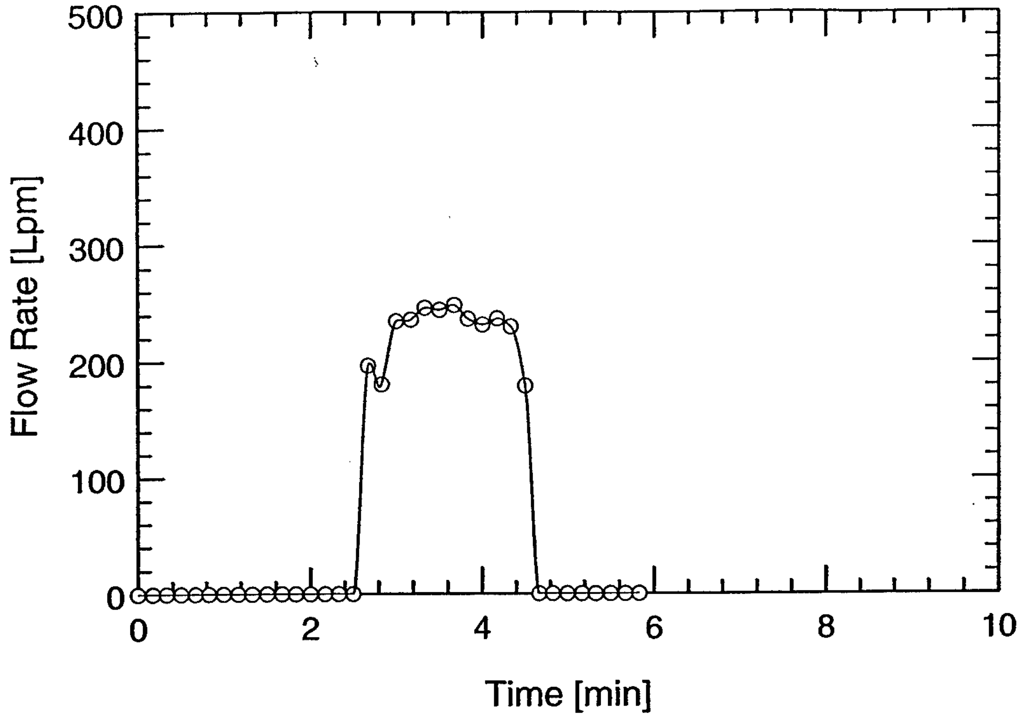


FR 22

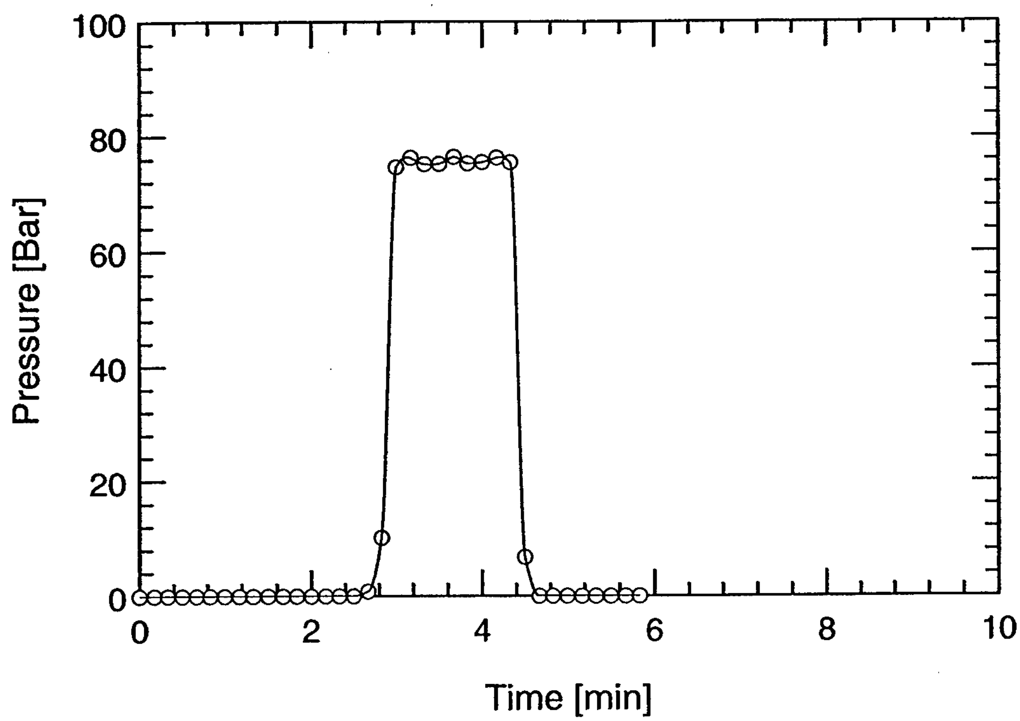


FR 22

Test #9

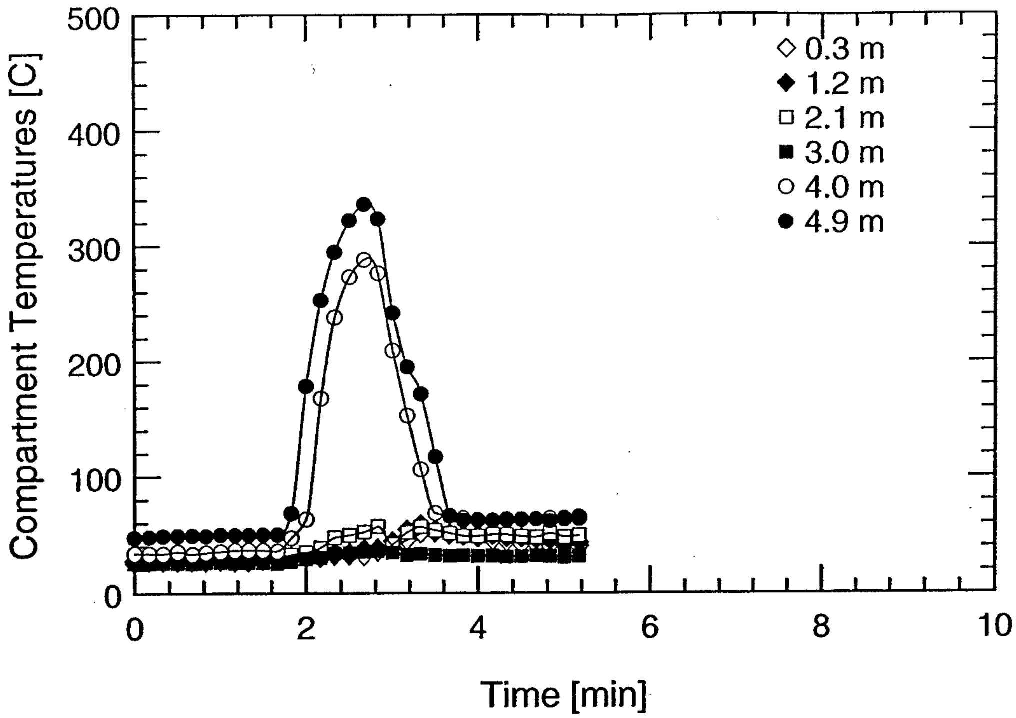


Water Mist System Flow Rate

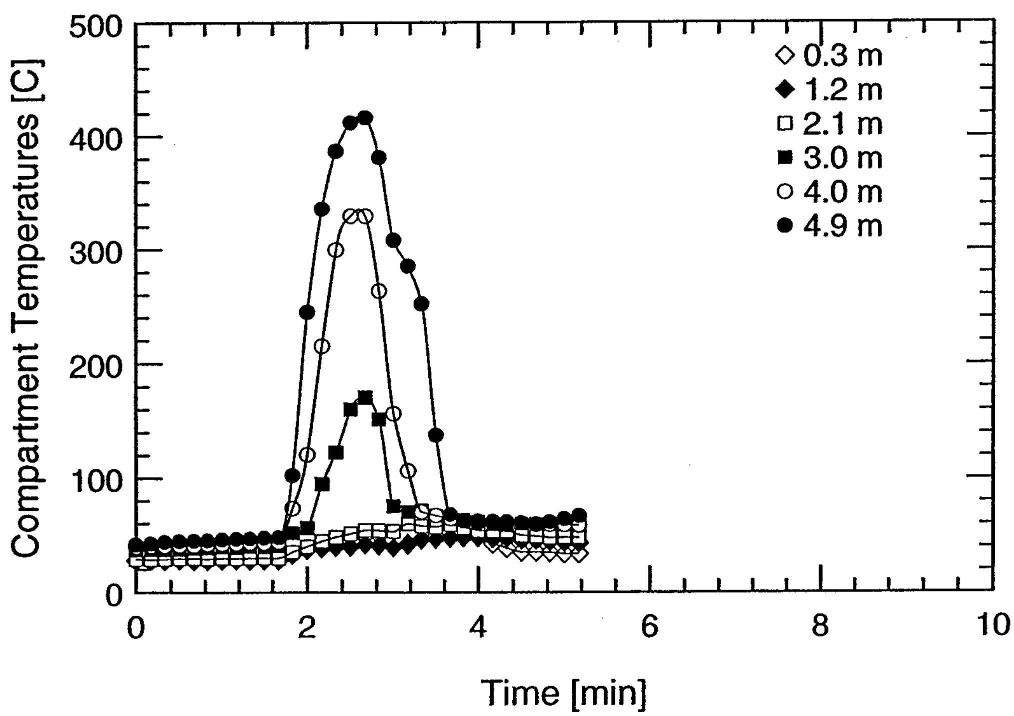


Water Mist System Pressure

Test #9

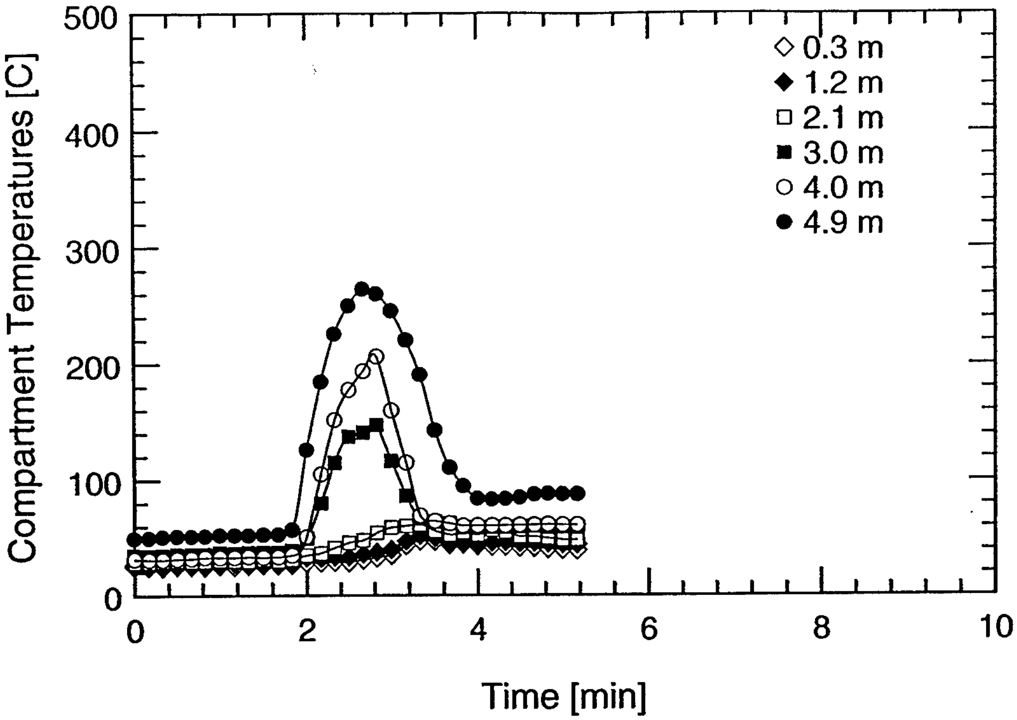


5-22-1

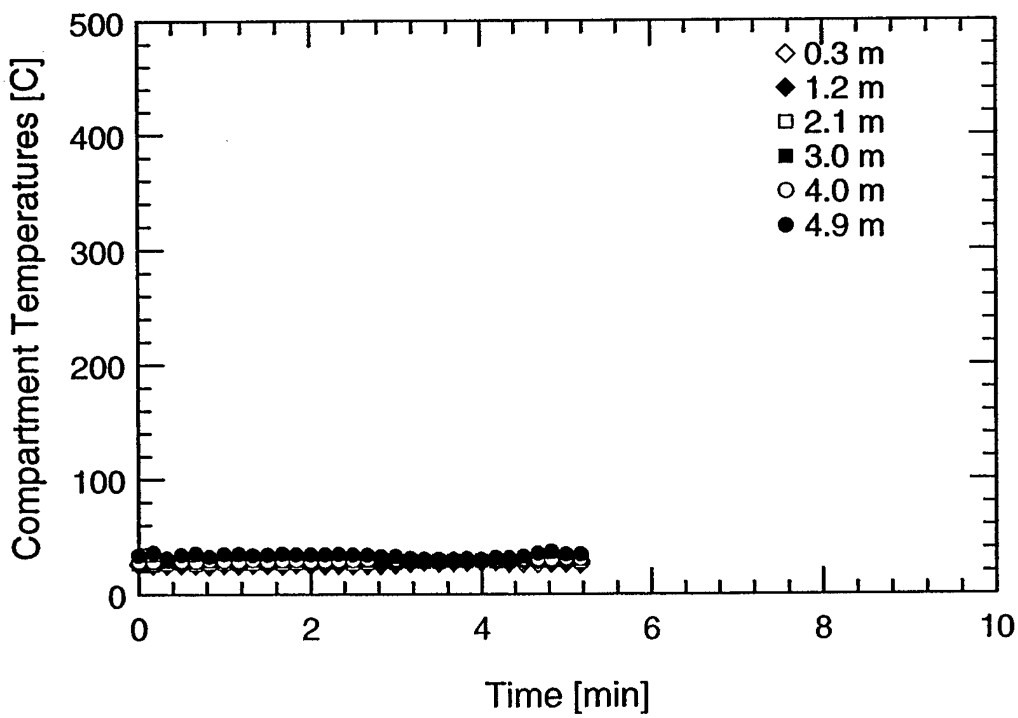


5-27-1

Test #10

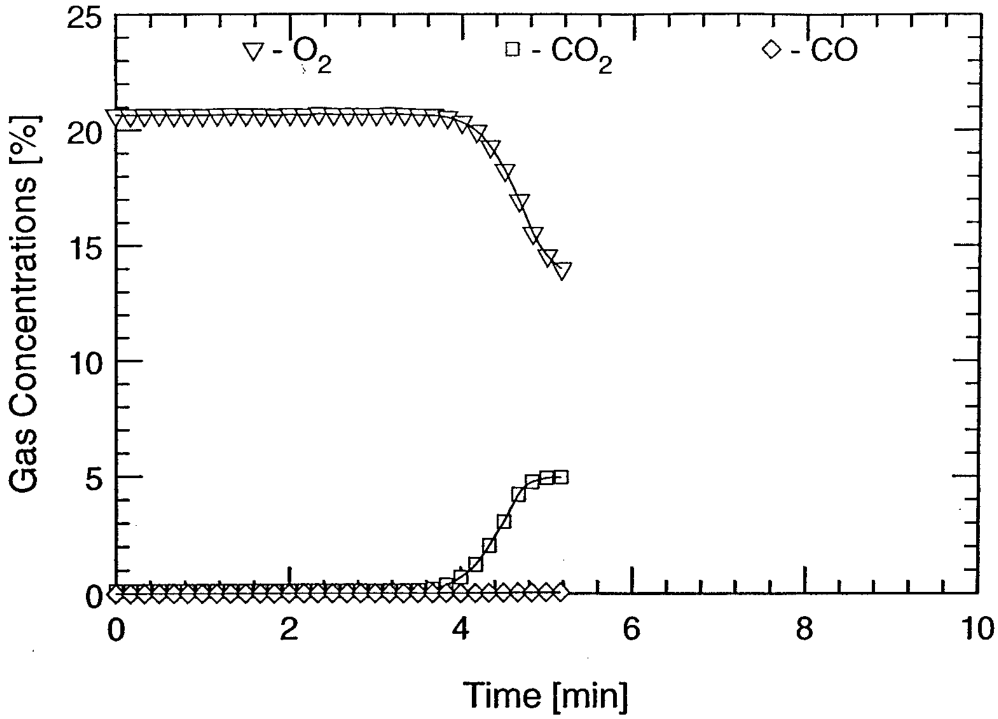


5-27-2

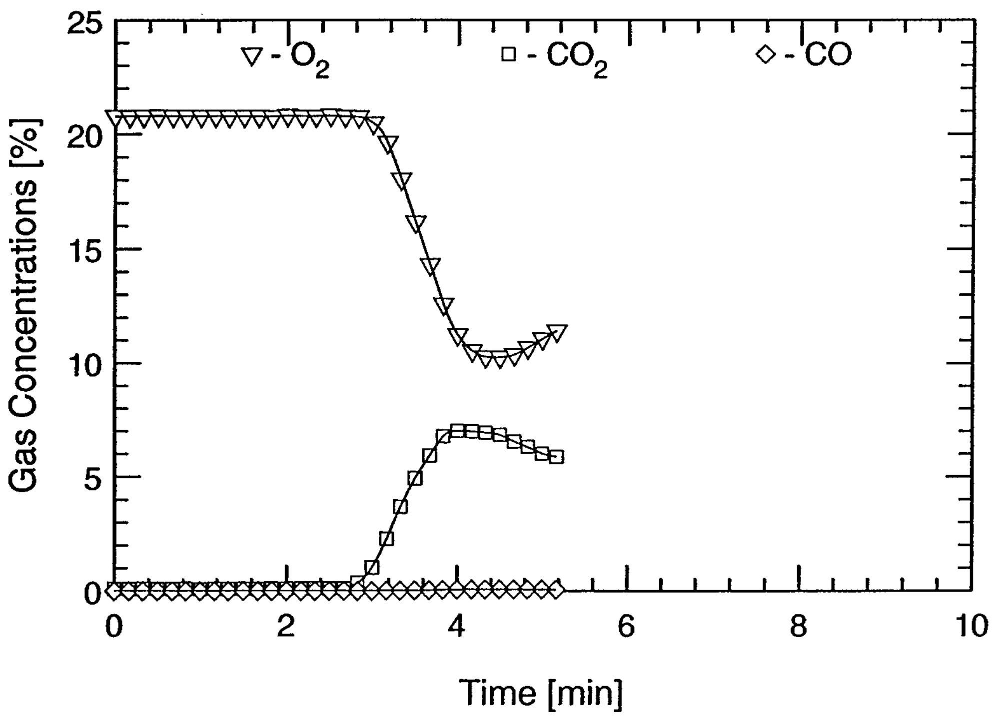


5-35-1

Test #10

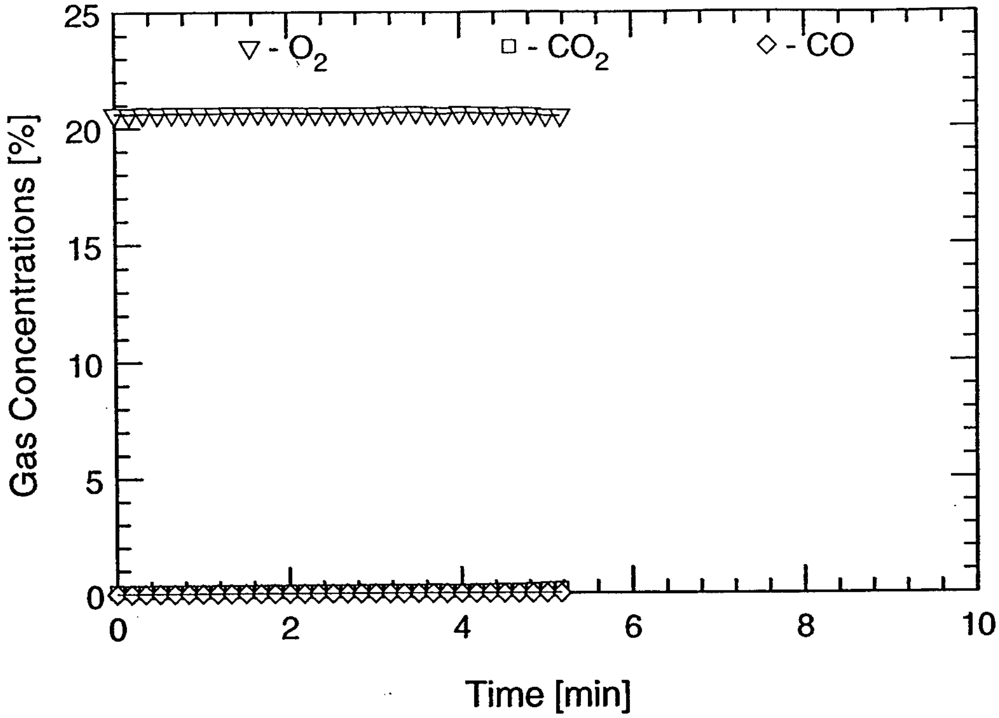


FR 22 - 0.5 m

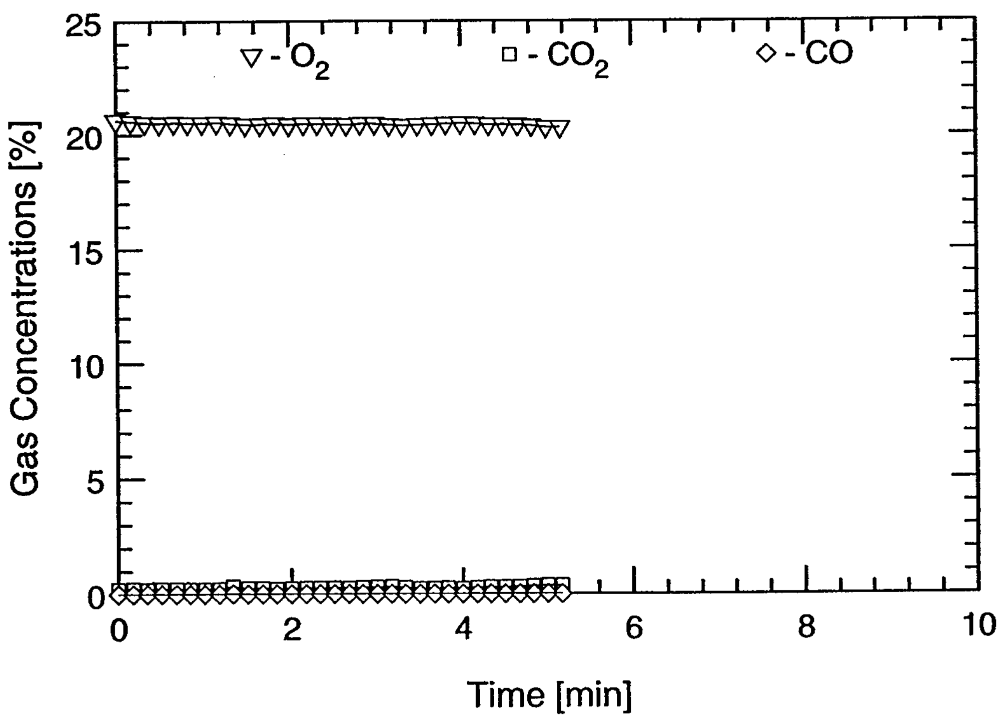


FR 22 - 4.5 m

Test #10

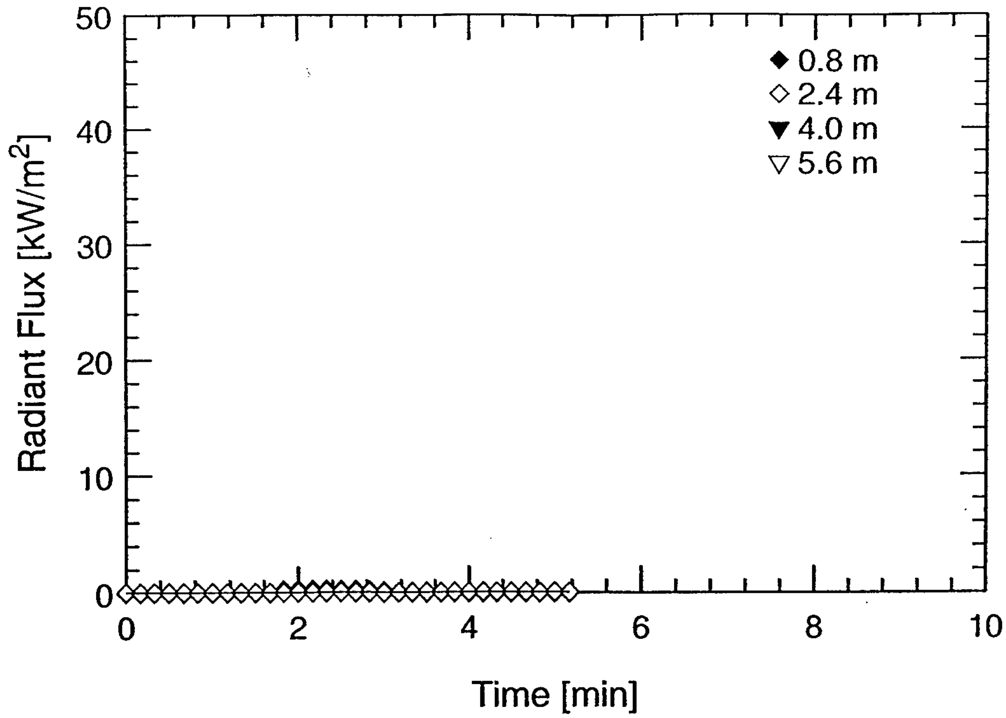


FR 36 - 0.5 m

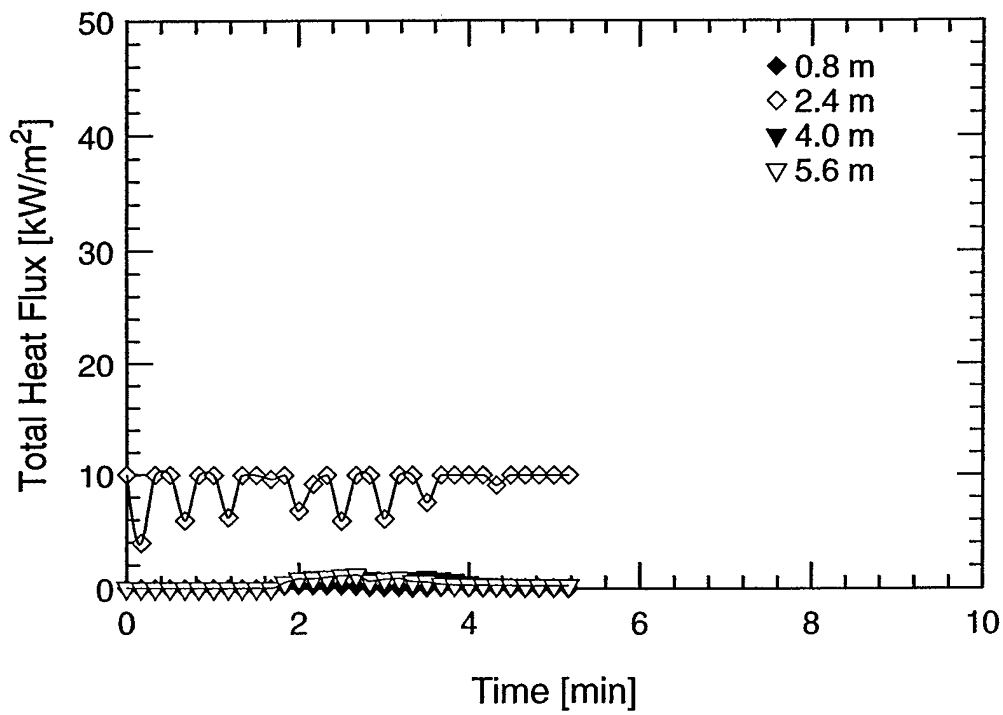


FR 36 - 4.5 m

Test #10

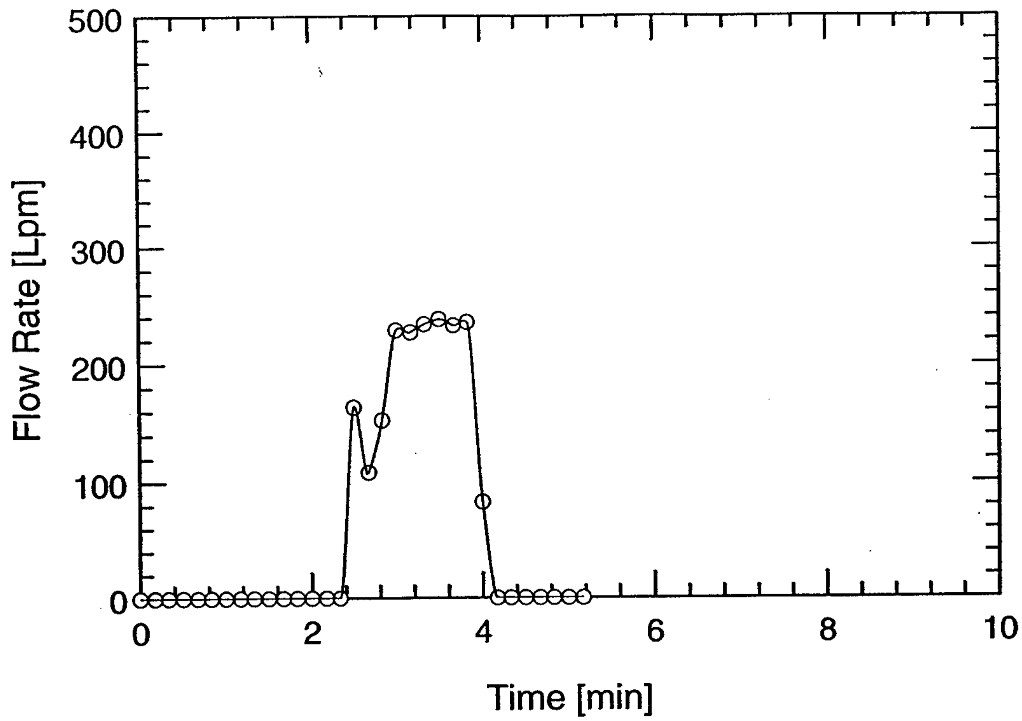


FR 22

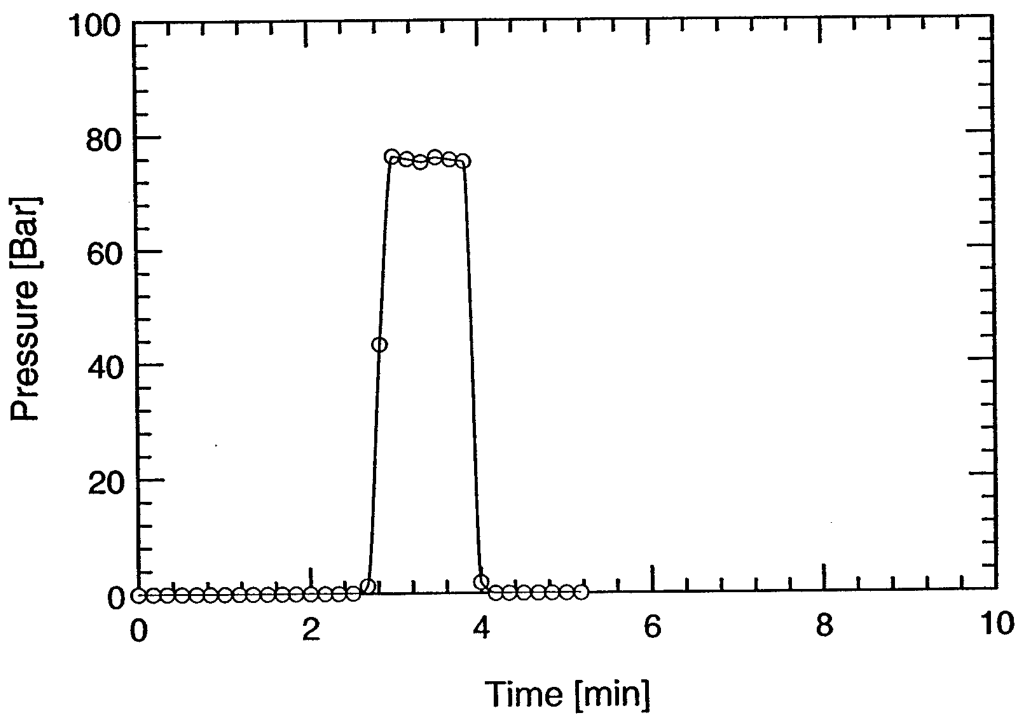


FR 22

Test #10

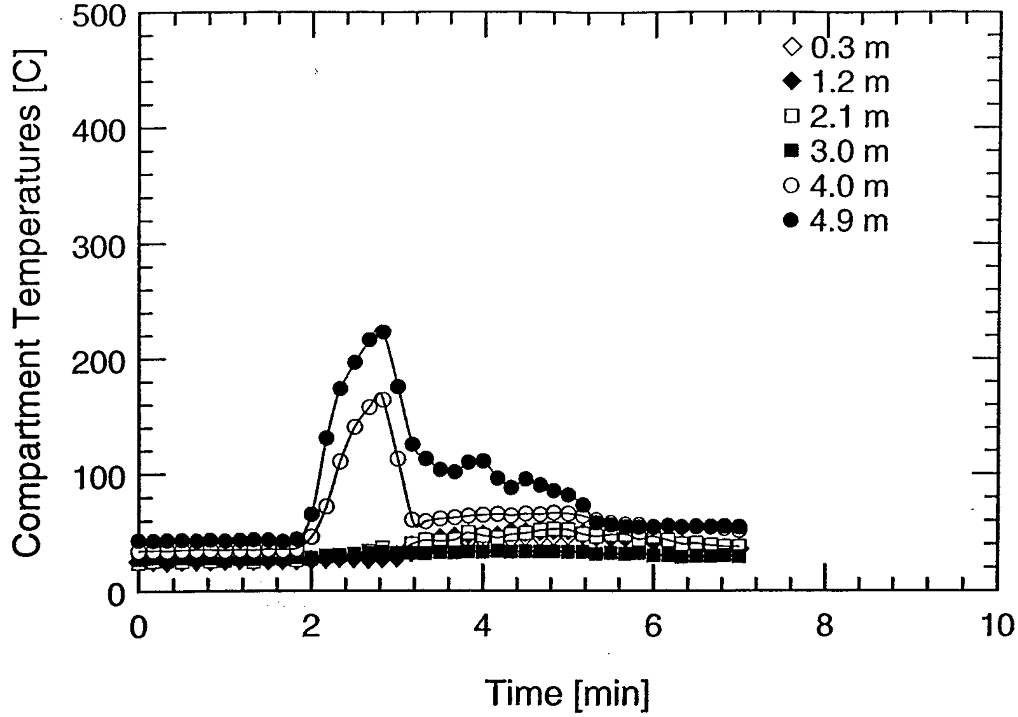


Water Mist System Flow Rate

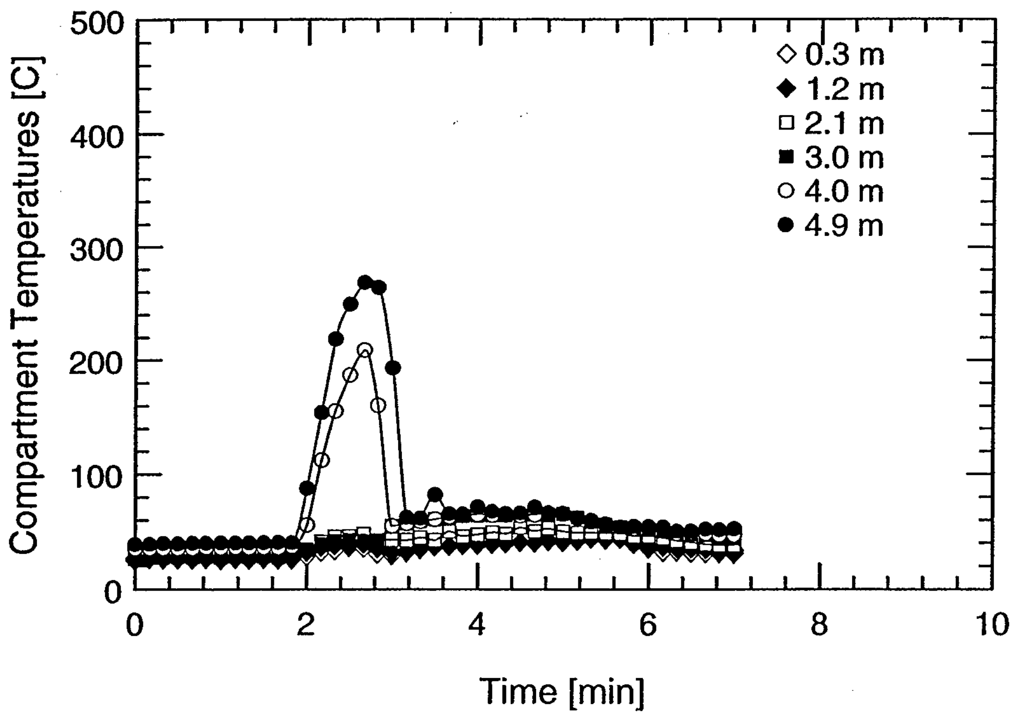


Water Mist System Pressure

Test #10

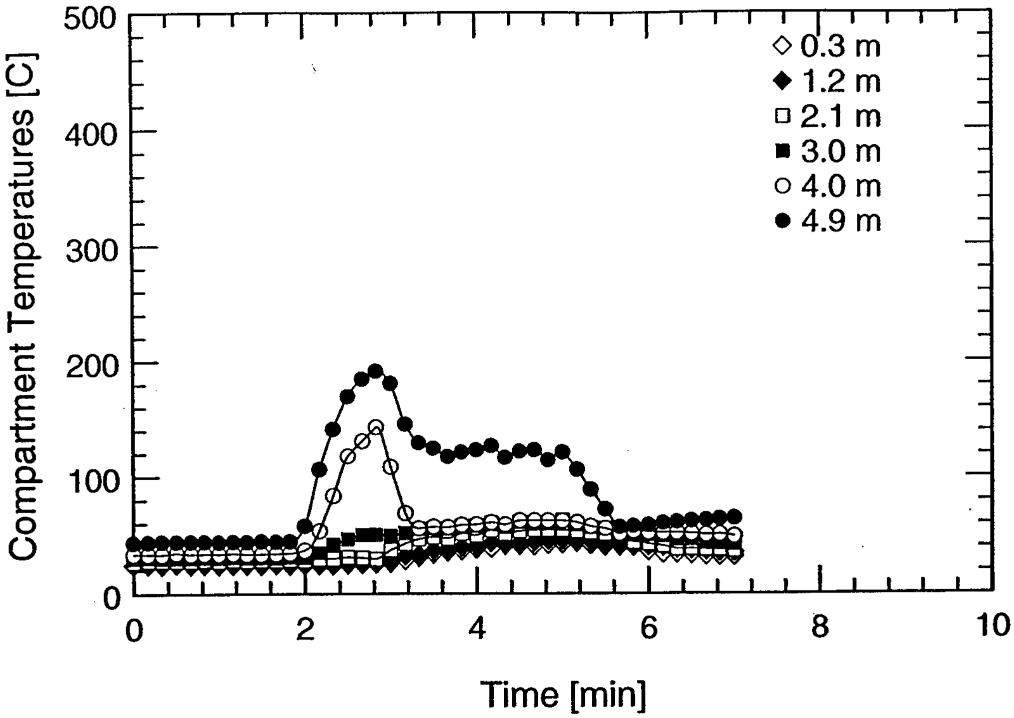


5-22-1

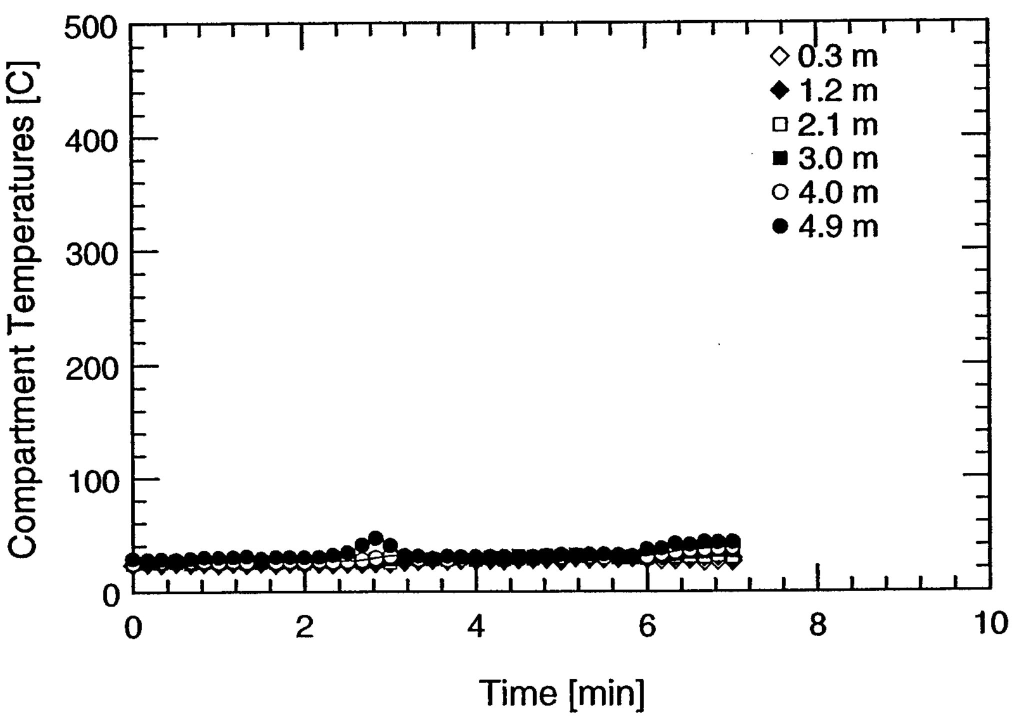


5-27-1

Test #11

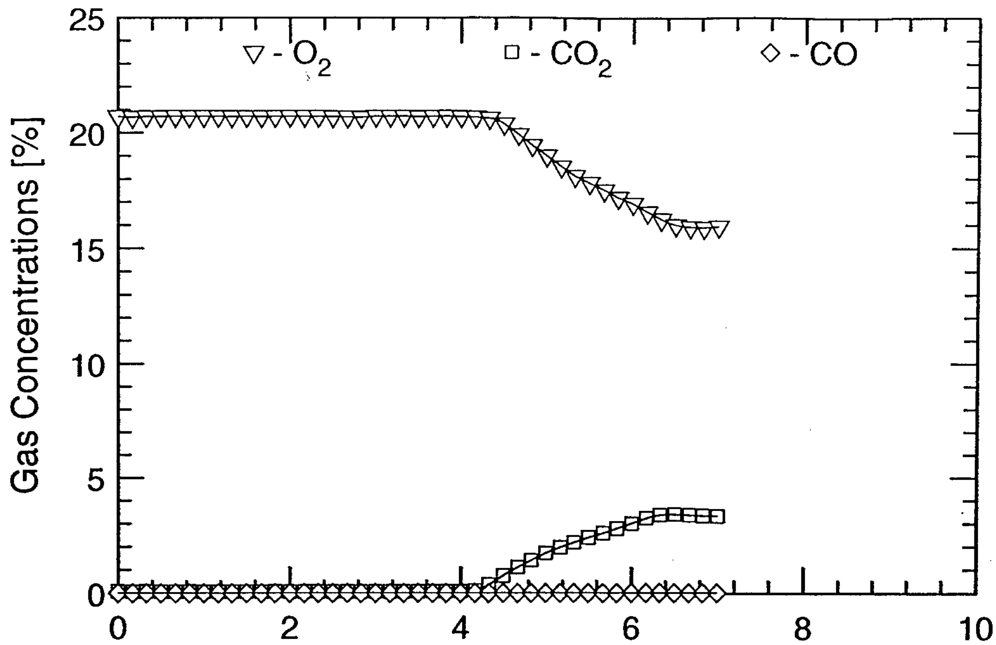


5-27-2

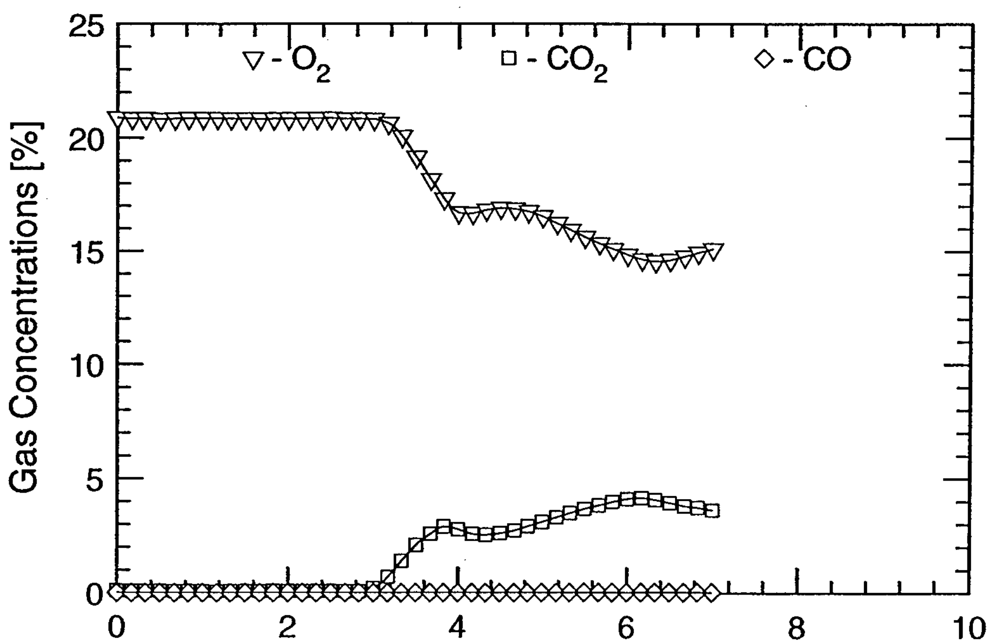


5-35-1

Test #11

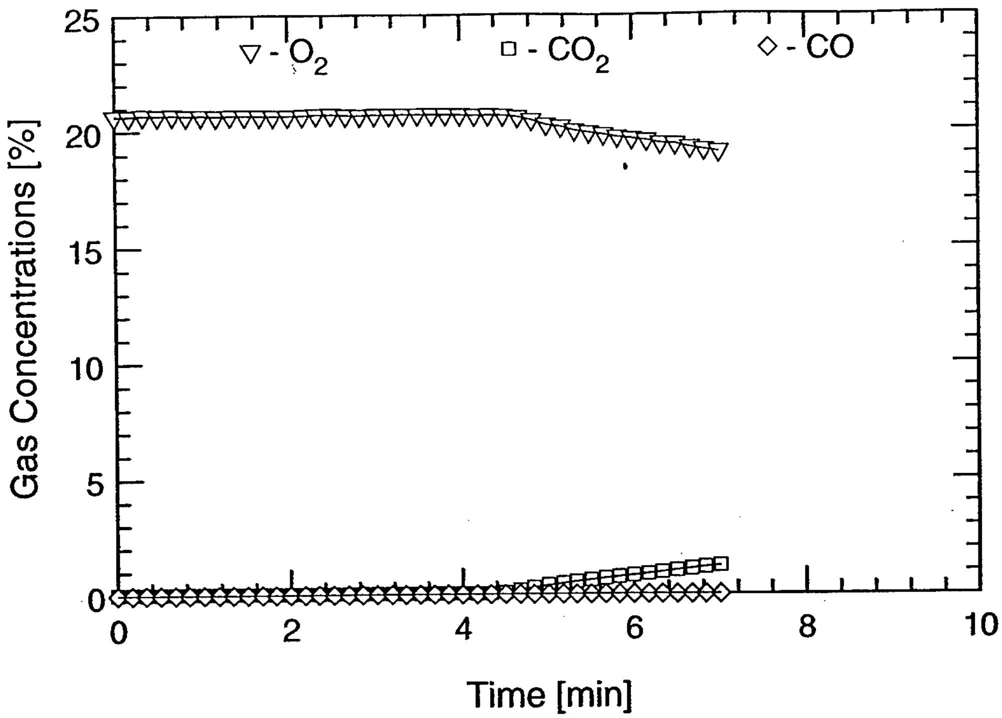


FR 22 - 0.5 m

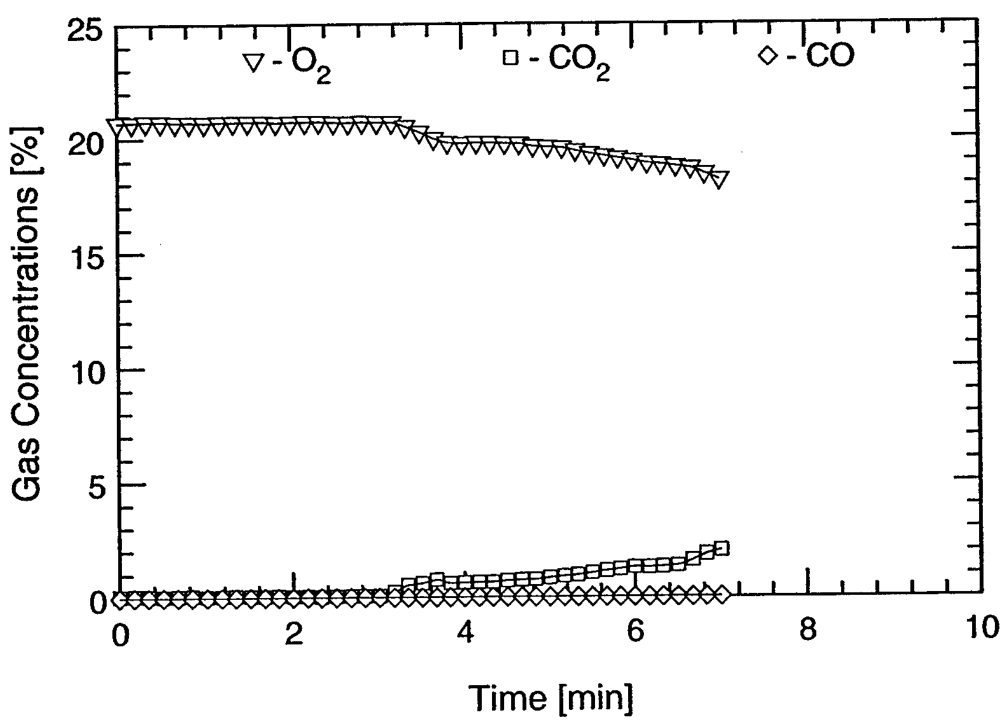


FR 22 - 4.5 m

Test #11

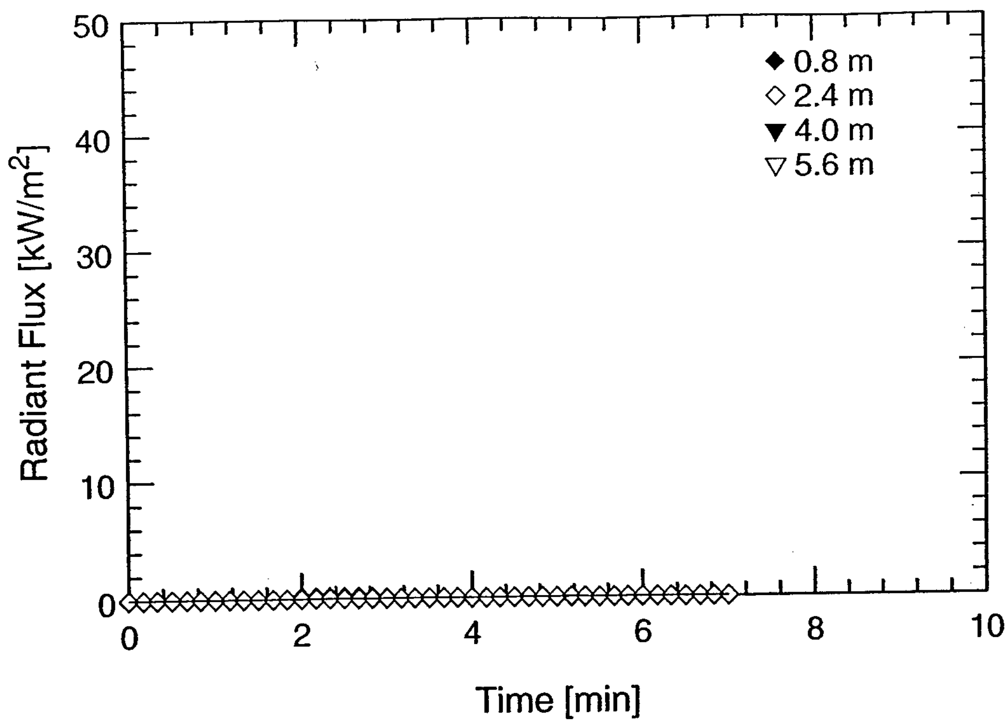


FR 36 - 0.5 m

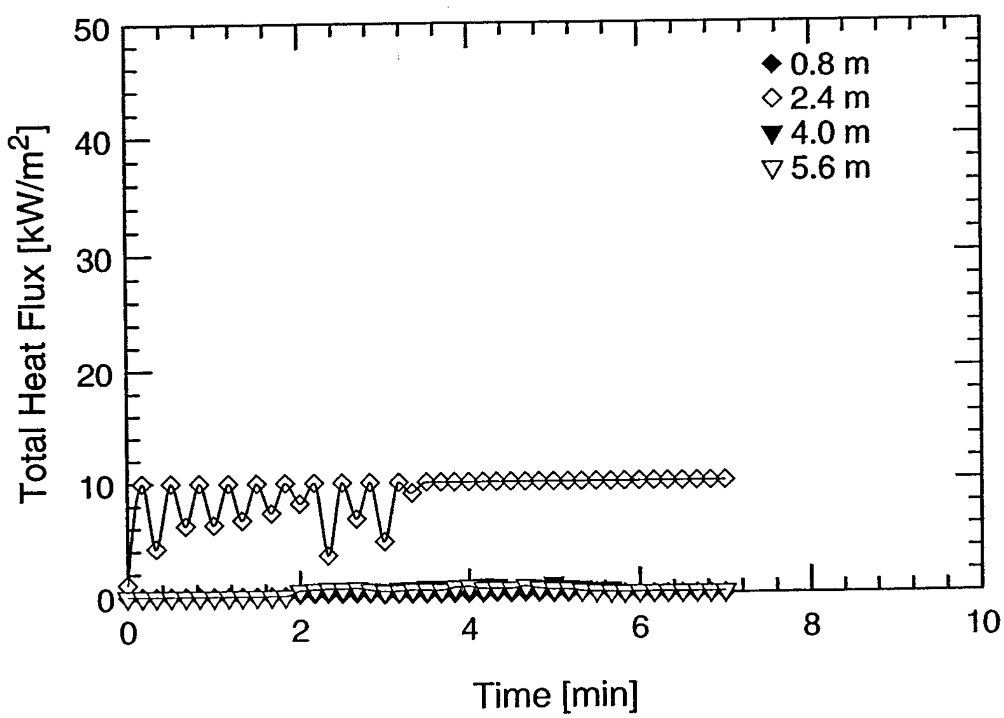


FR 36 - 4.5 m

Test #11

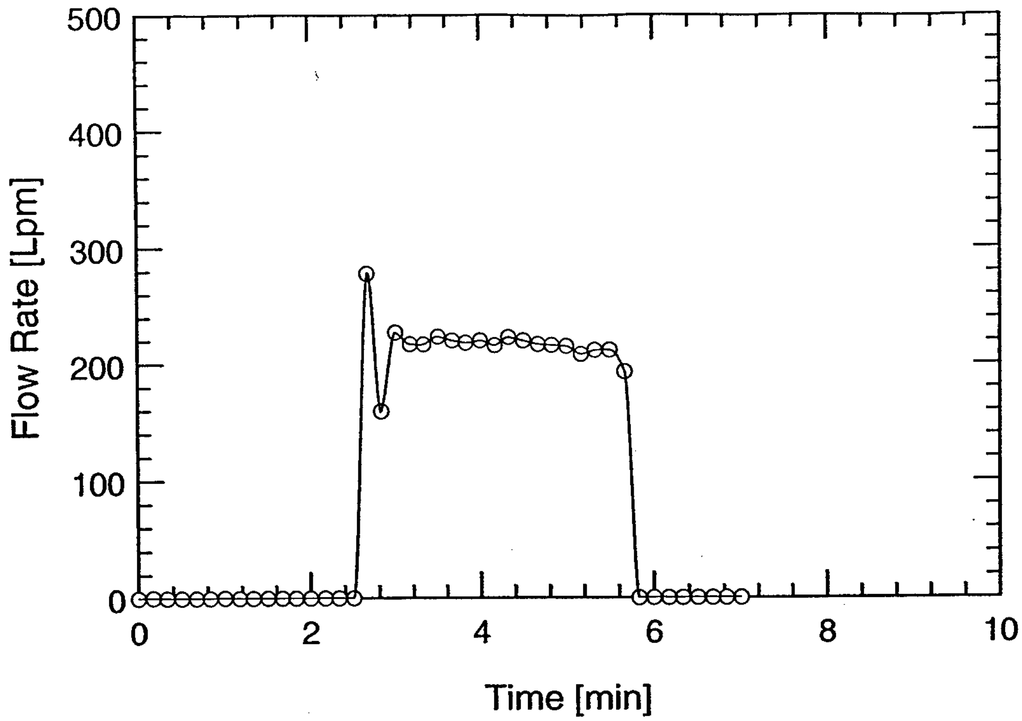


FR 22

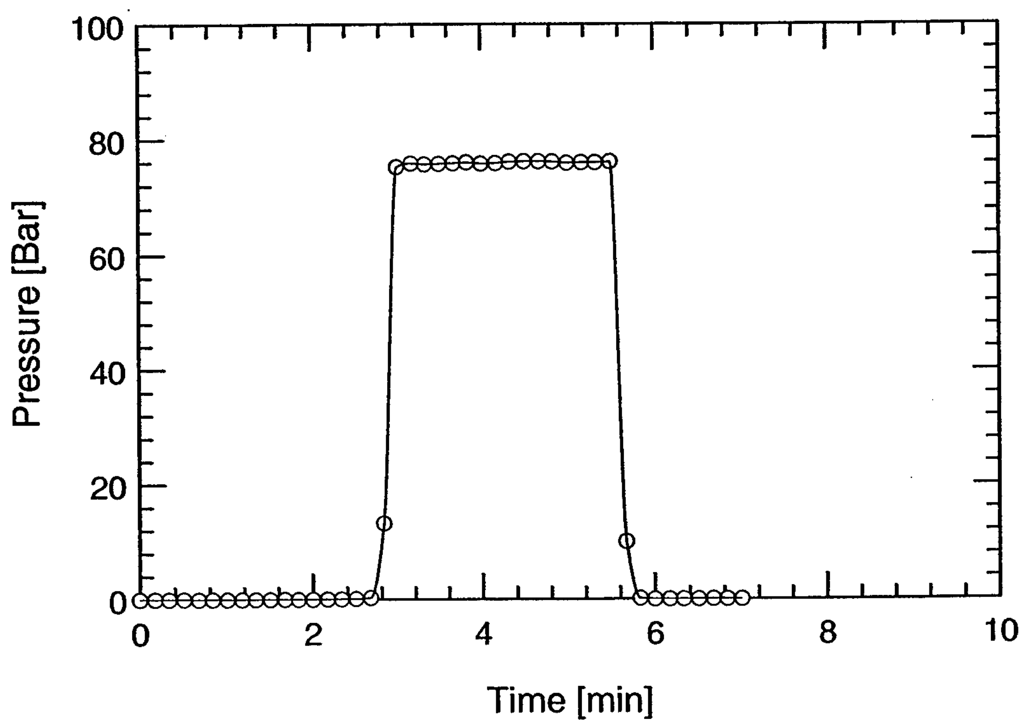


FR 22

Test #11

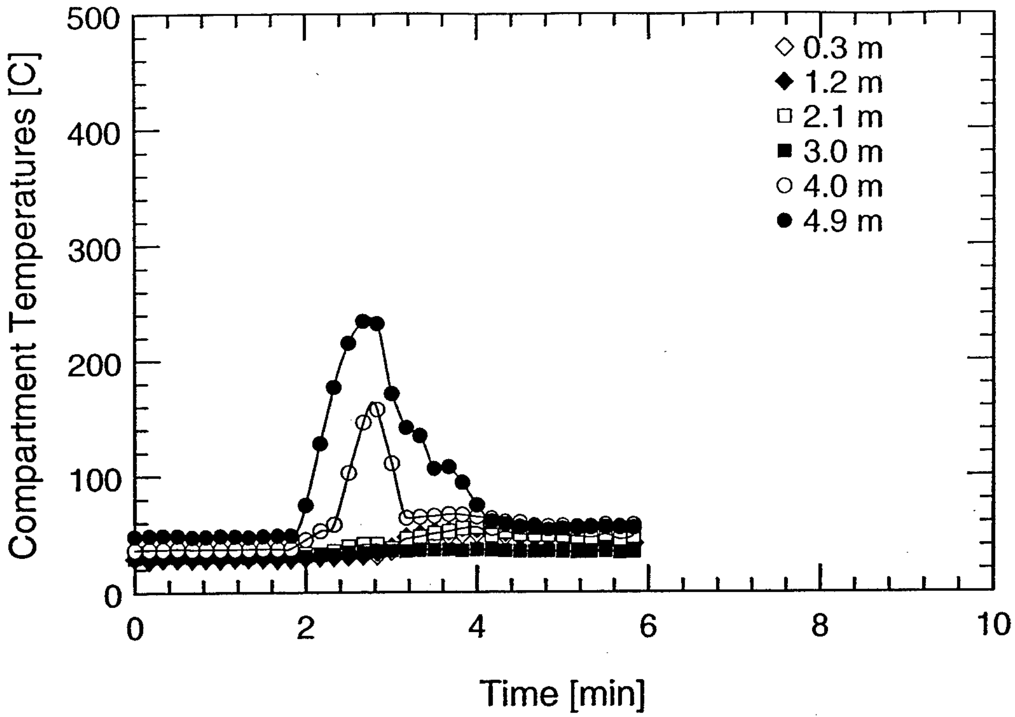


Water Mist System Flow Rate

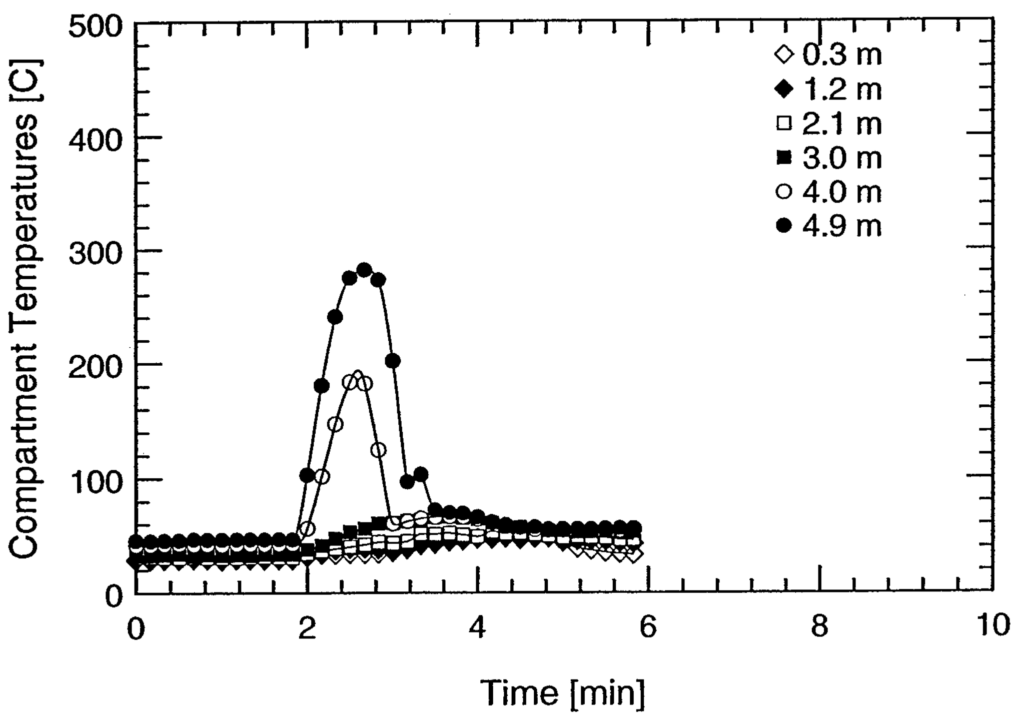


Water Mist System Pressure

Test #11

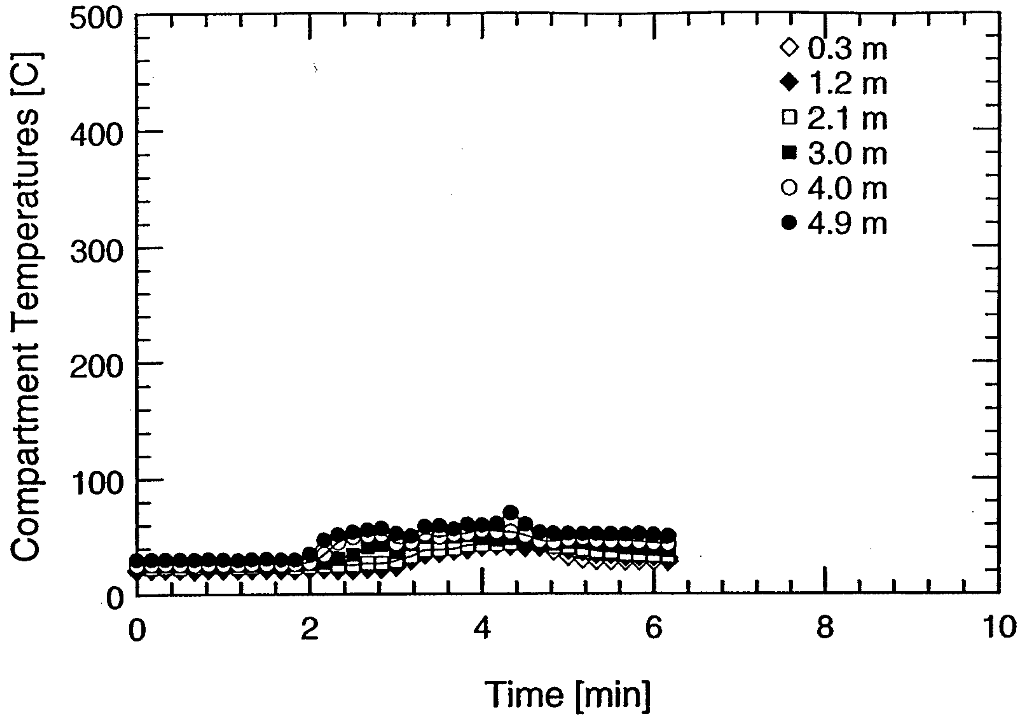


5-22-1

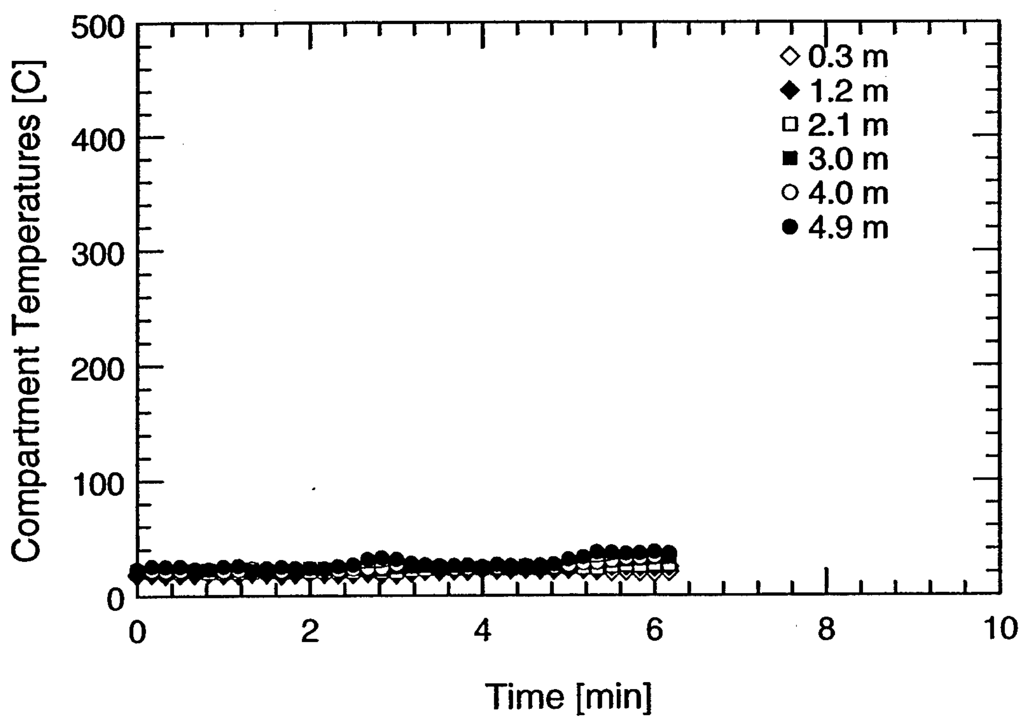


5-27-1

Test #12

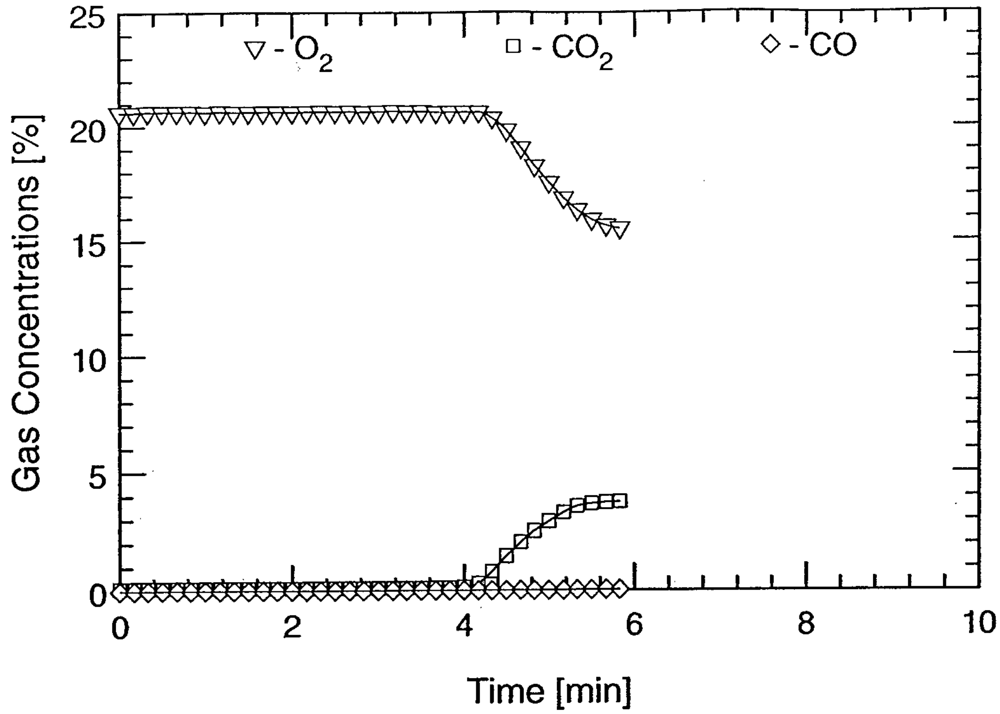


5-27-2

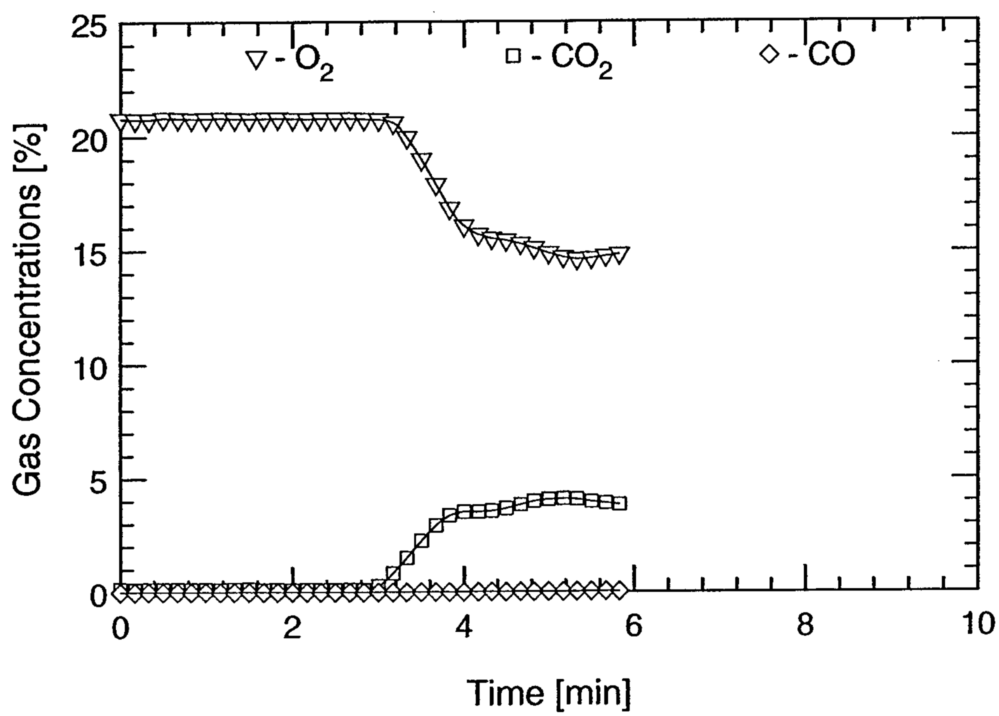


5-35-1

Test #12

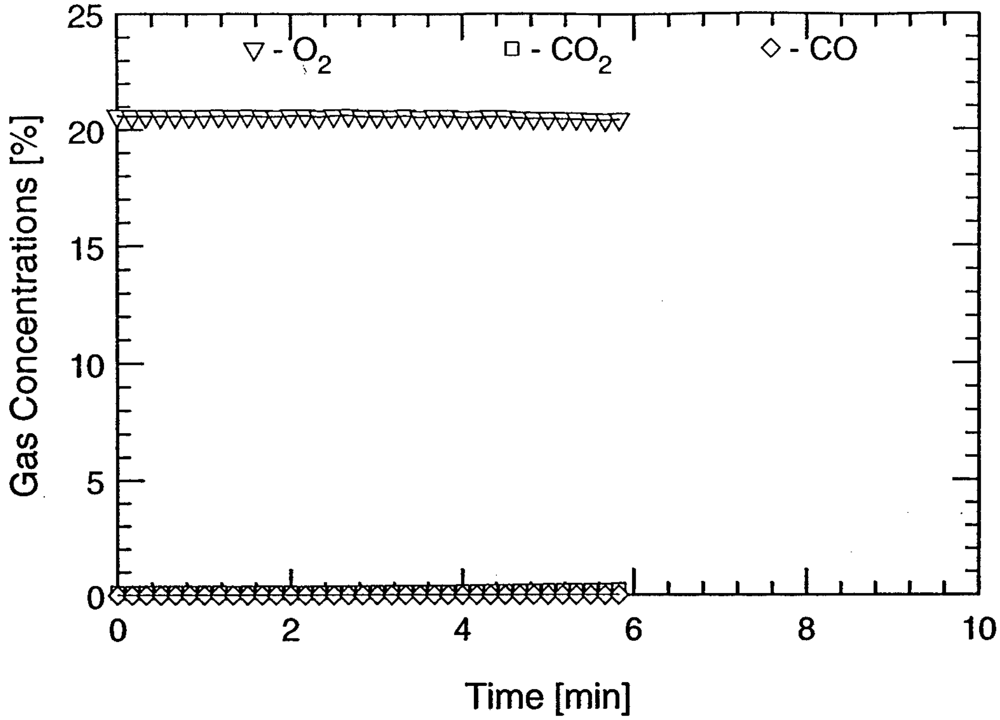


FR 22 - 0.5 m

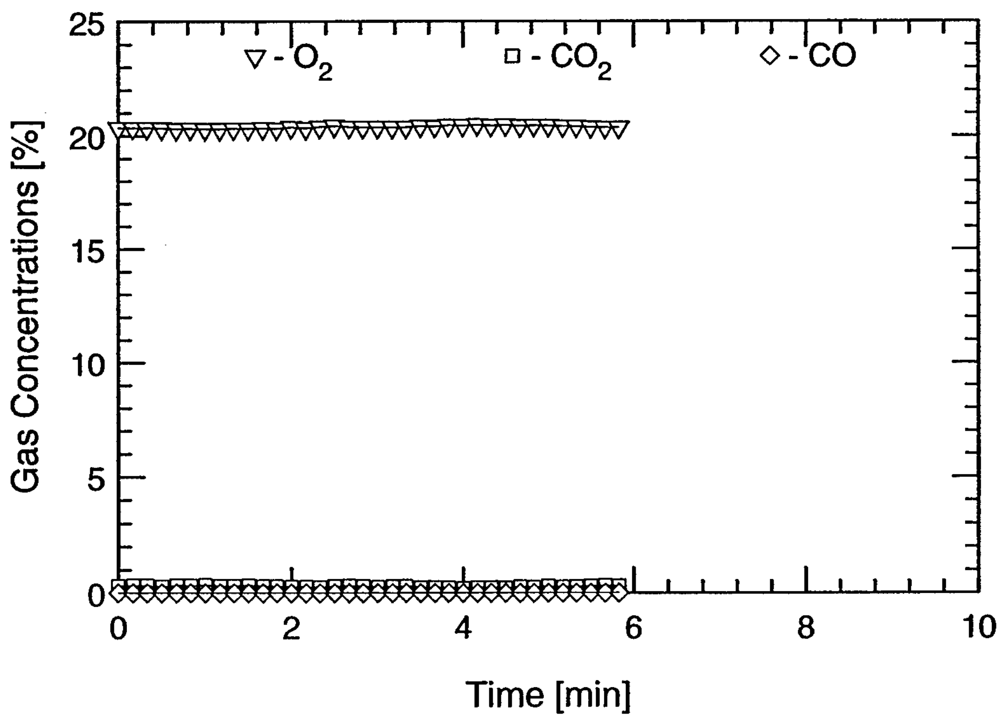


FR 22 - 4.5 m

Test #12

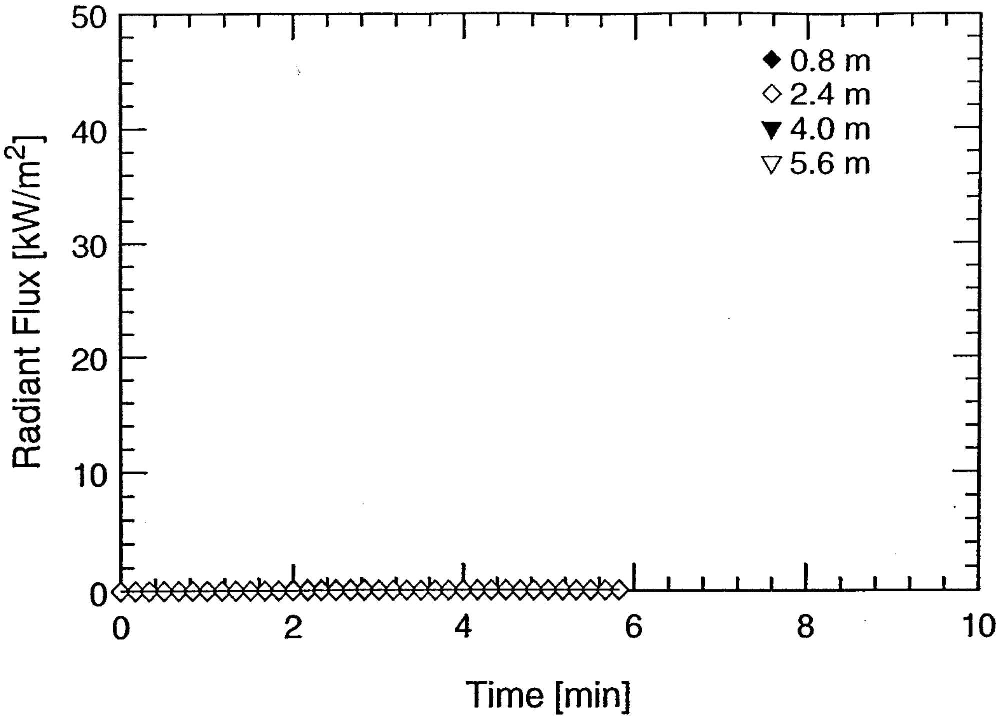


FR 36 - 0.5 m

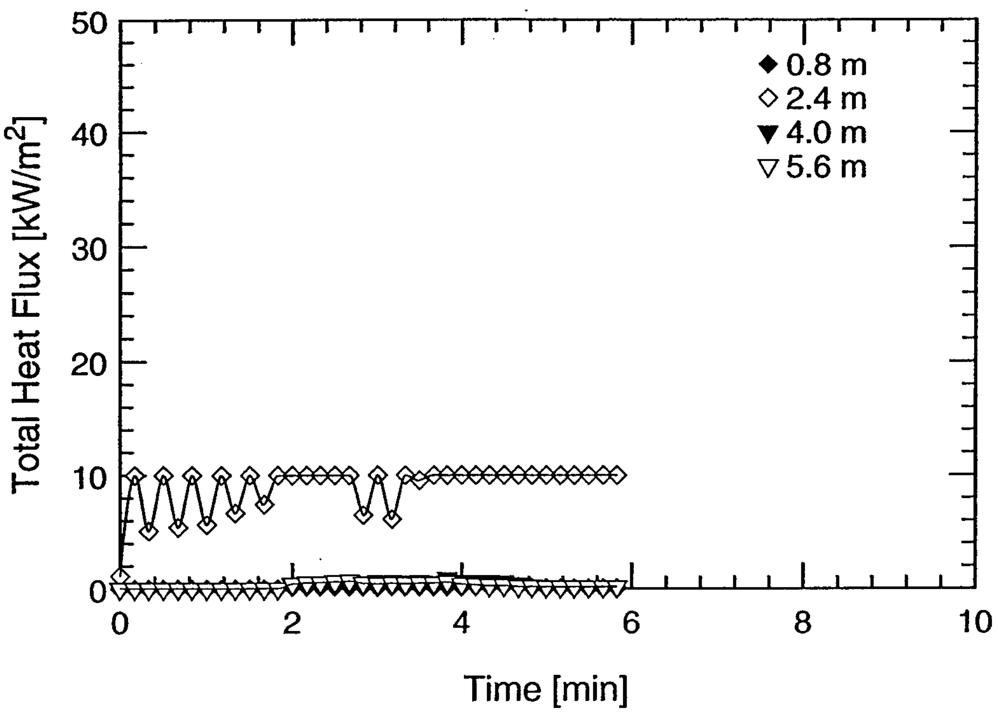


FR 36 - 4.5 m

Test #12

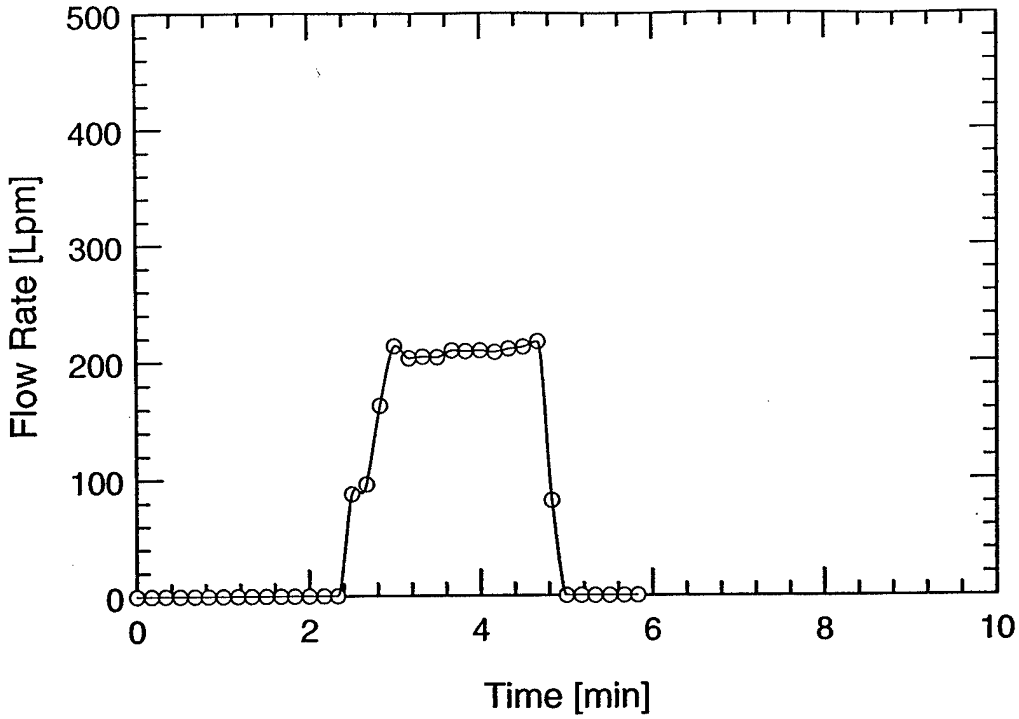


FR 22

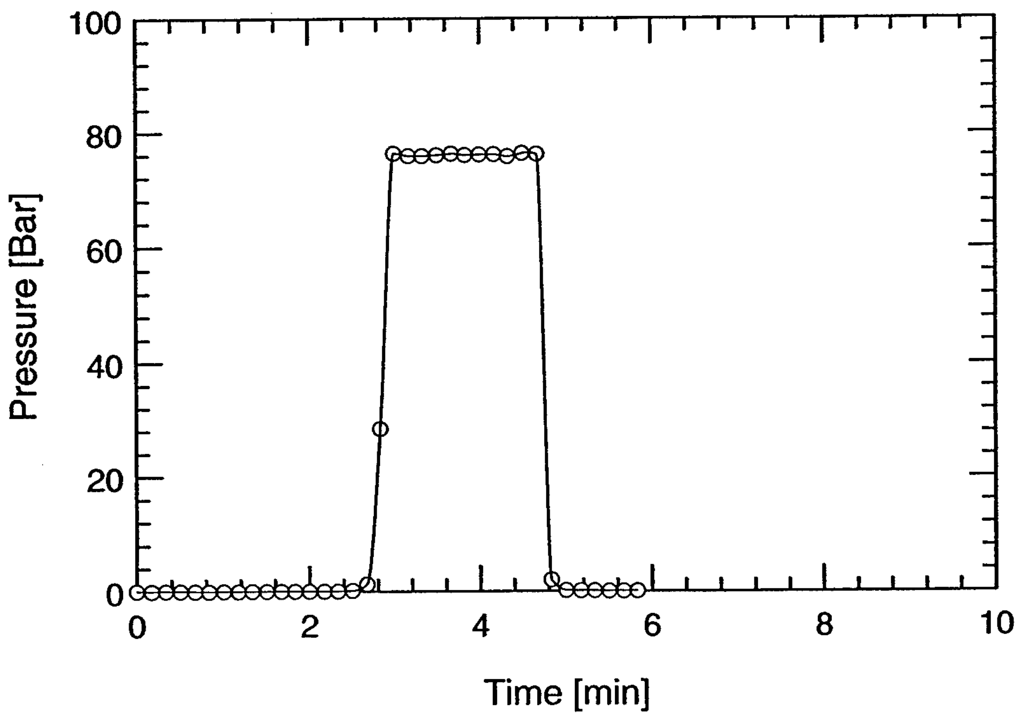


FR 22

Test #12

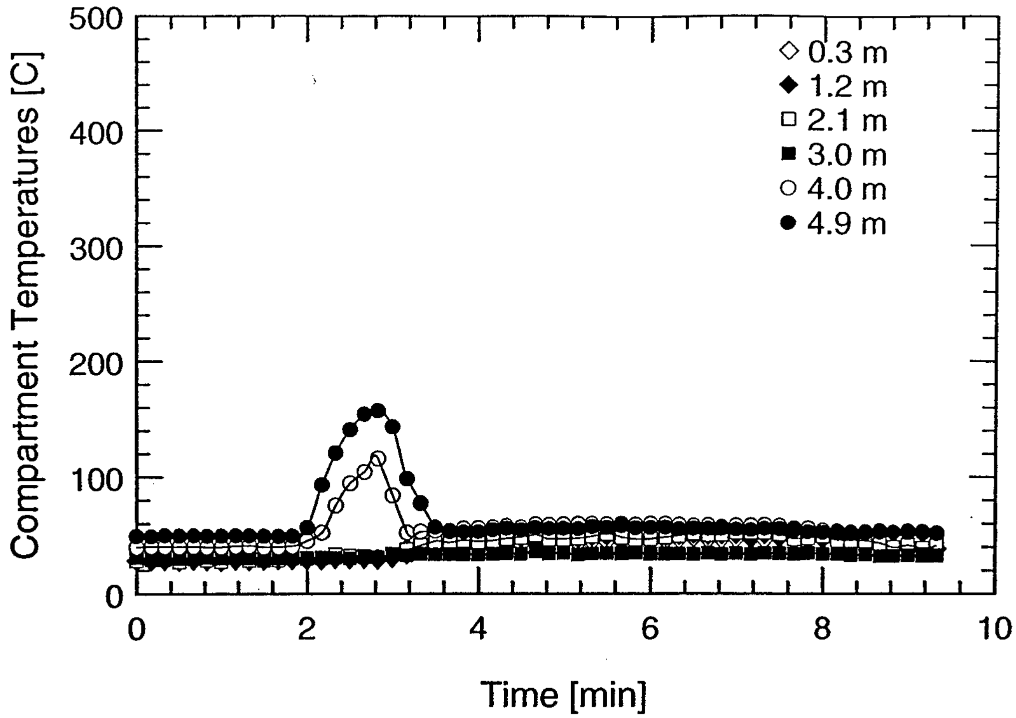


Water Mist System Flow Rate

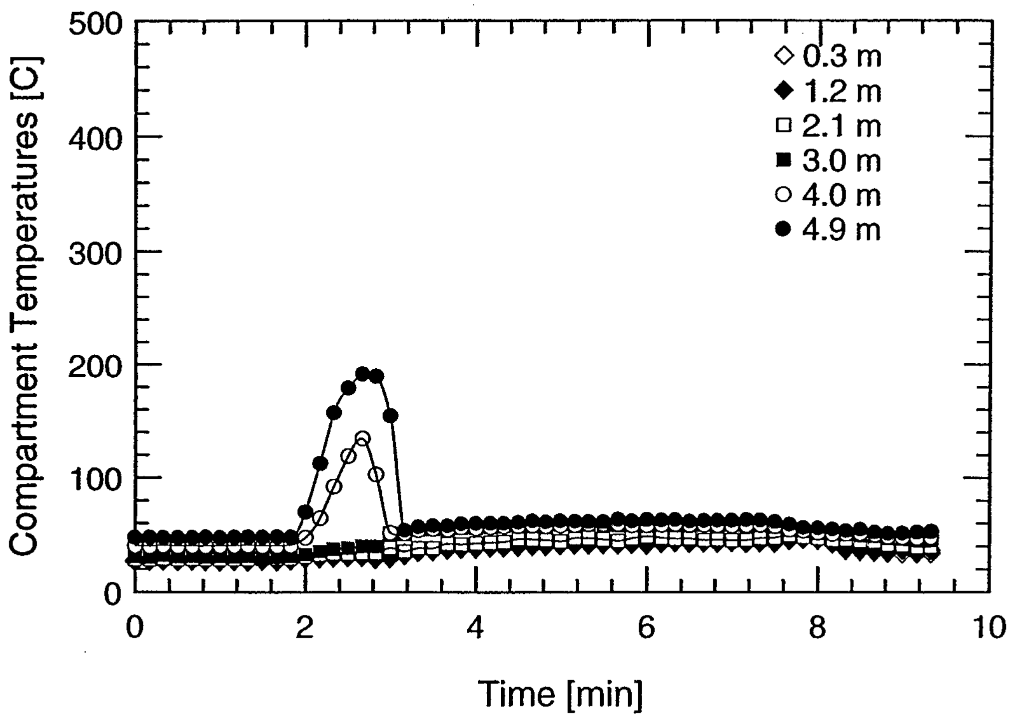


Water Mist System Pressure

Test #12

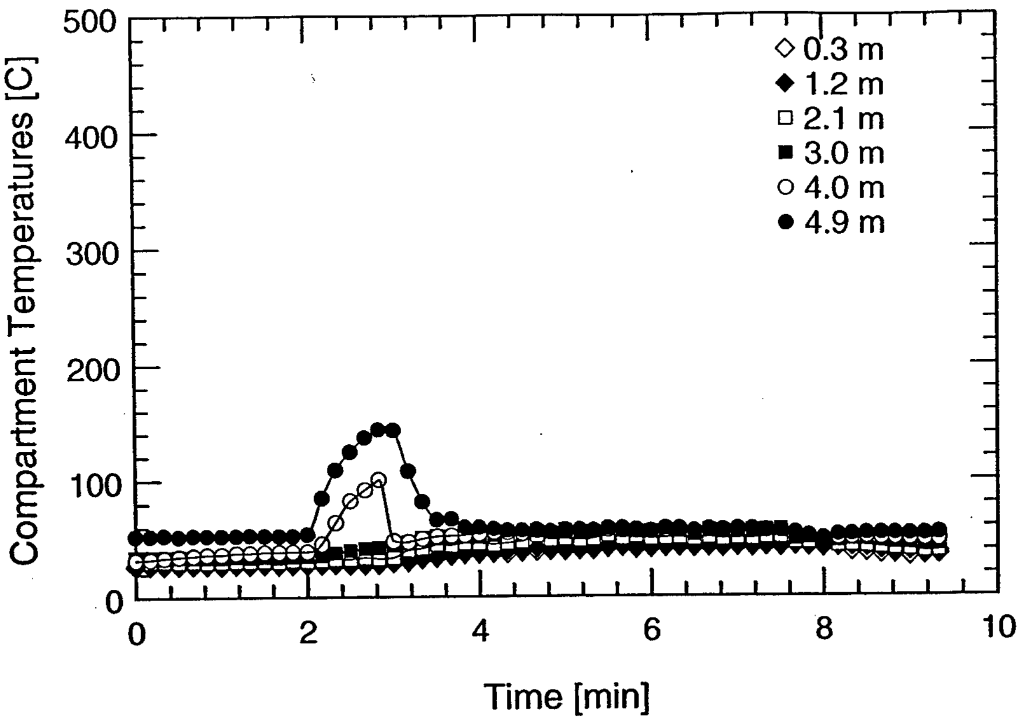


5-22-1

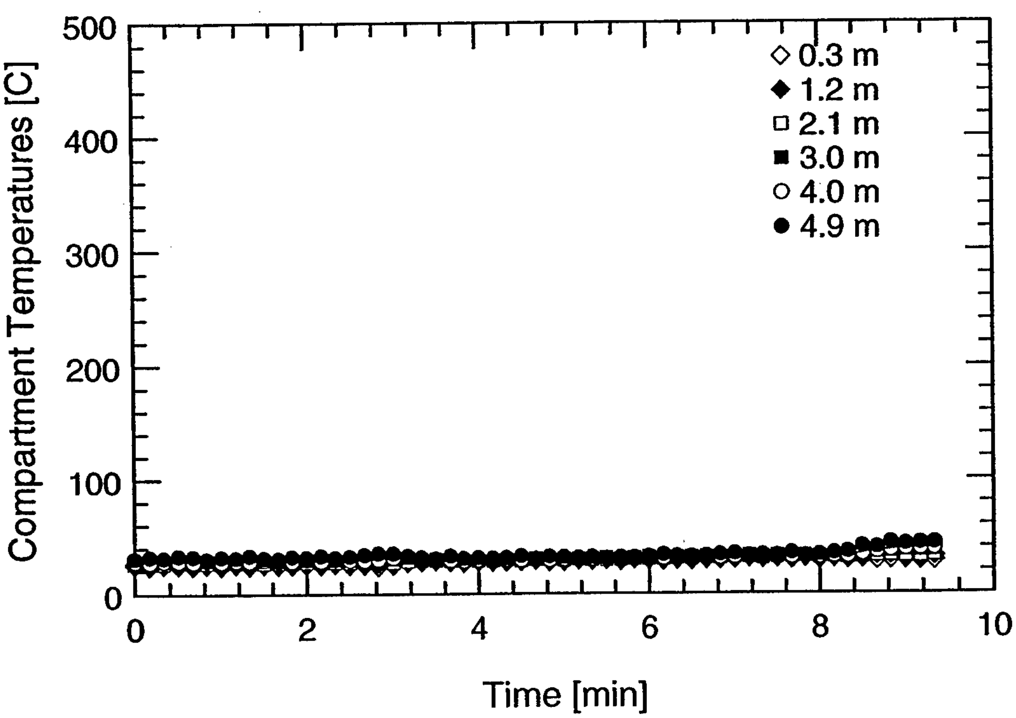


5-27-1

Test #13

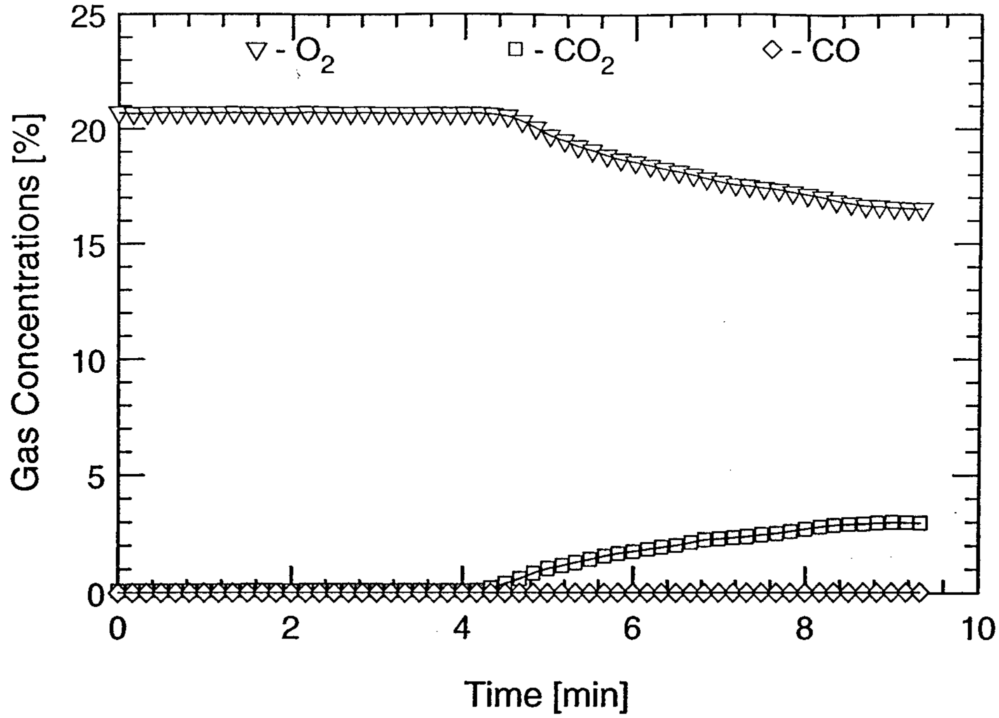


5-27-2

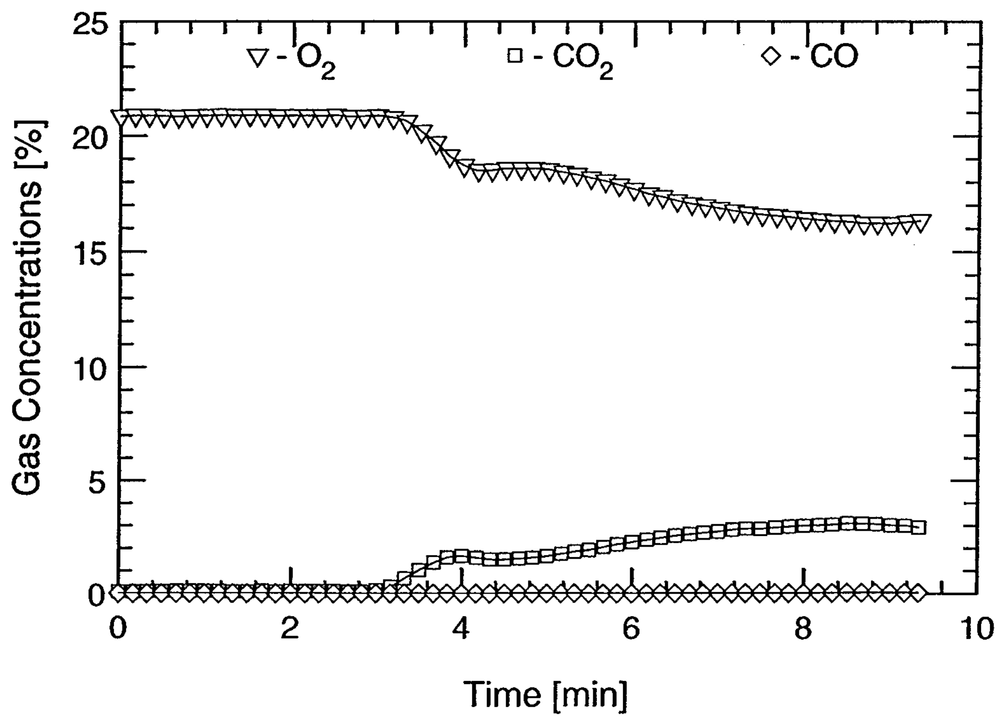


5-35-1

Test #13

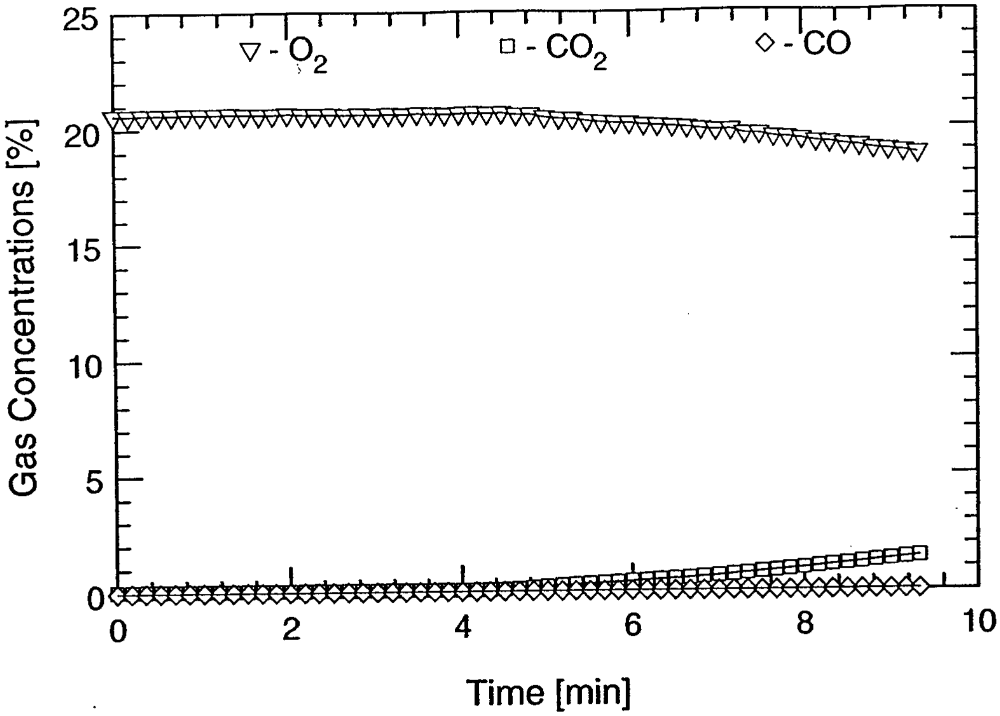


FR 22 - 0.5 m

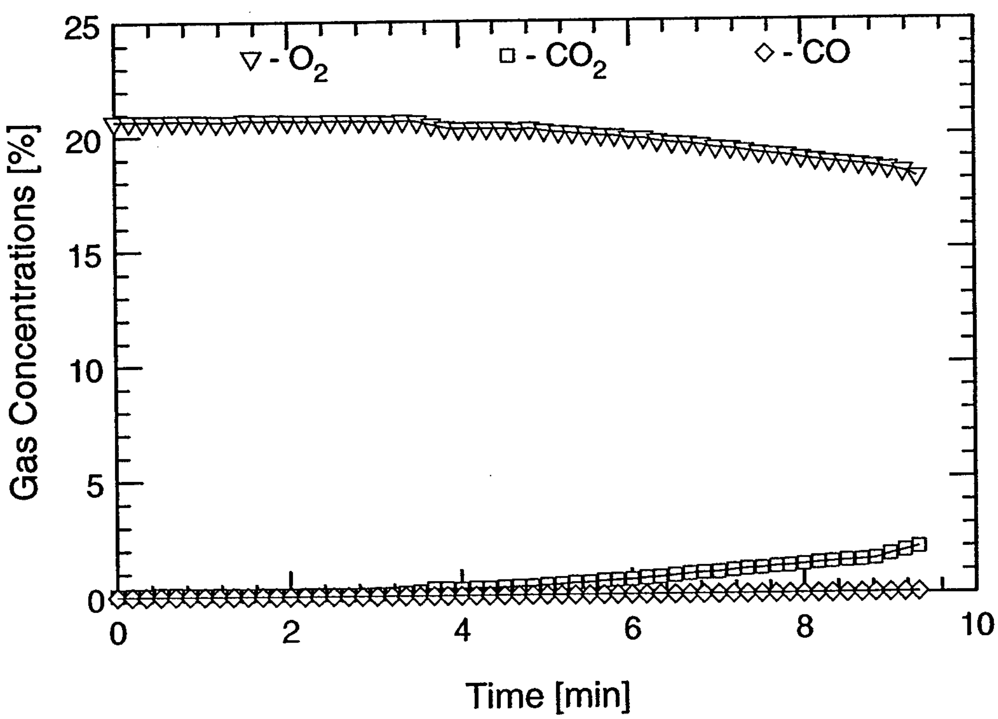


FR 22 - 4.5 m

Test #13

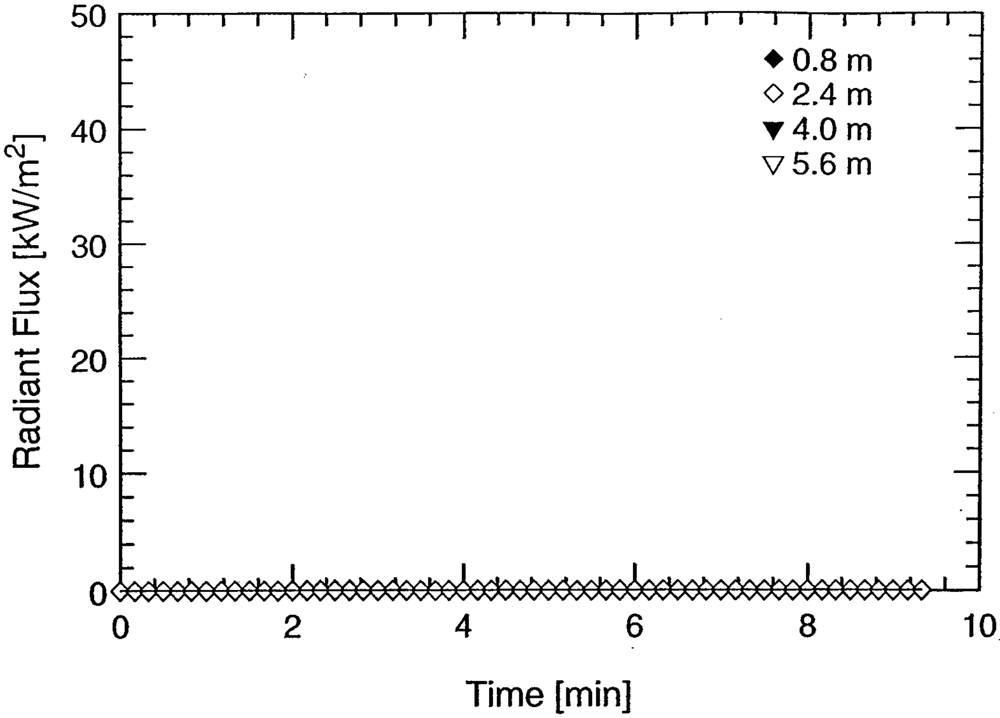


FR 36 - 0.5 m

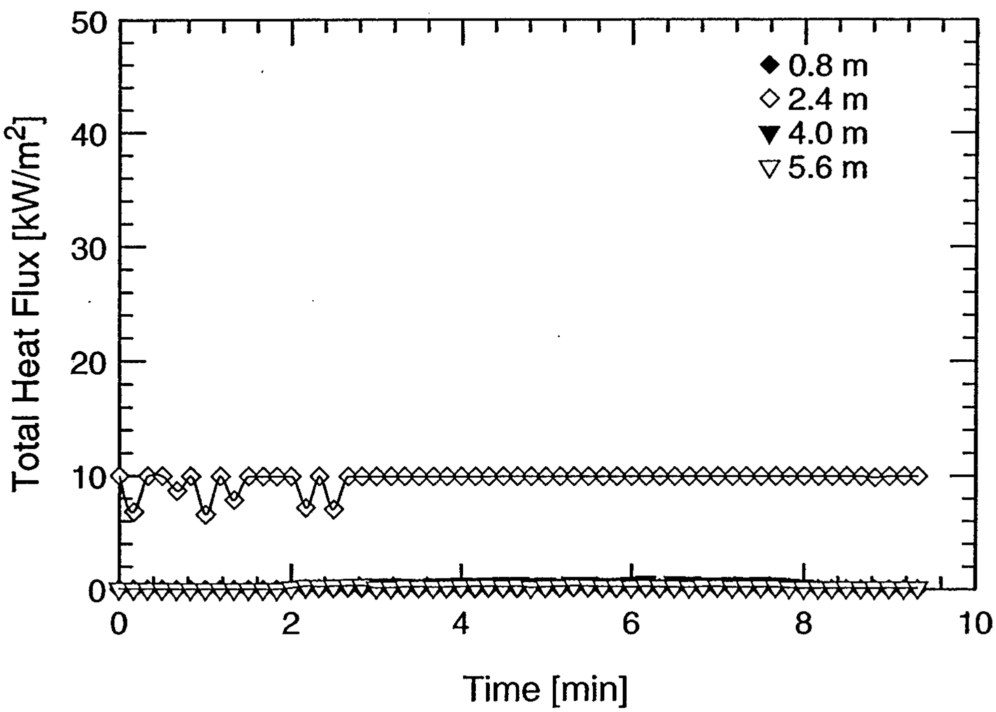


FR 36 - 4.5 m

Test #13

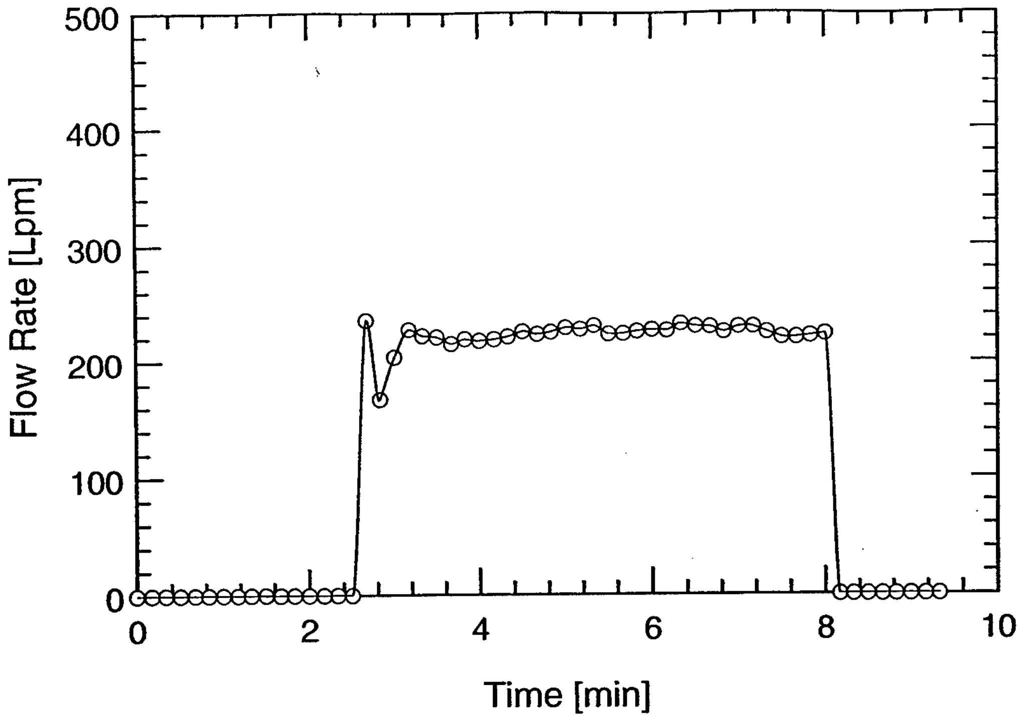


FR 22

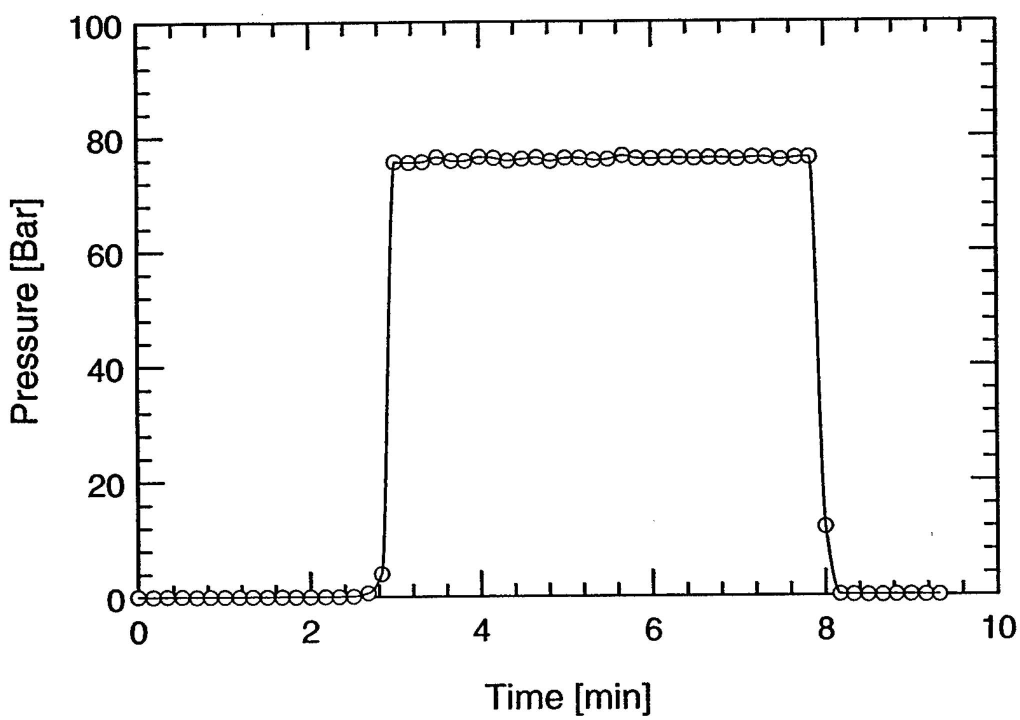


FR 22

Test #13

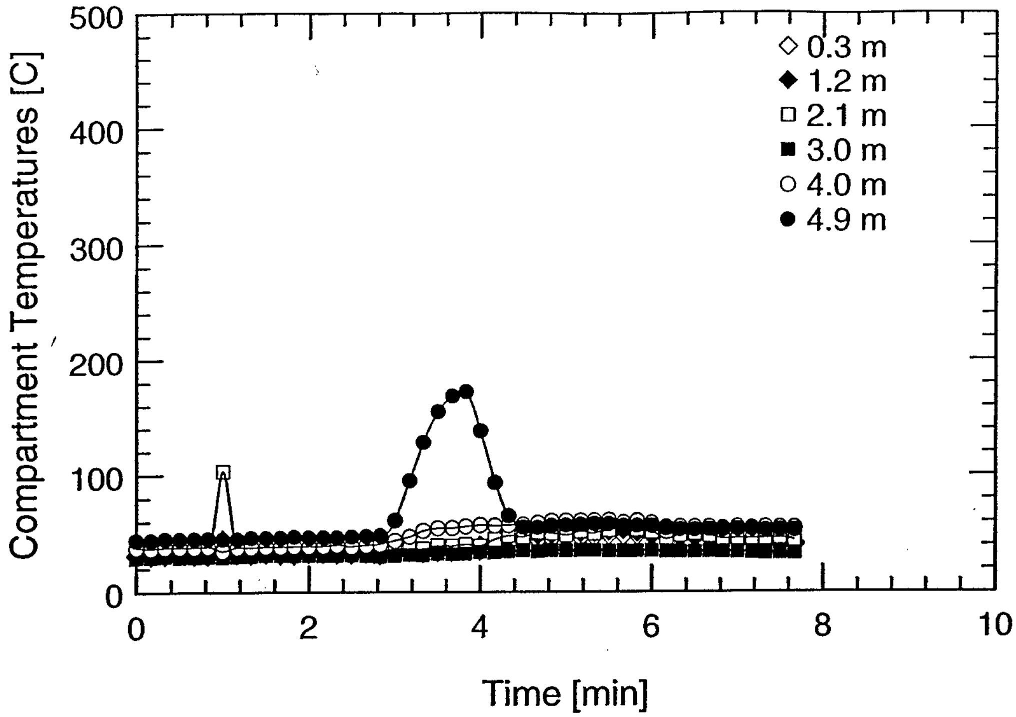


Water Mist System Flow Rate

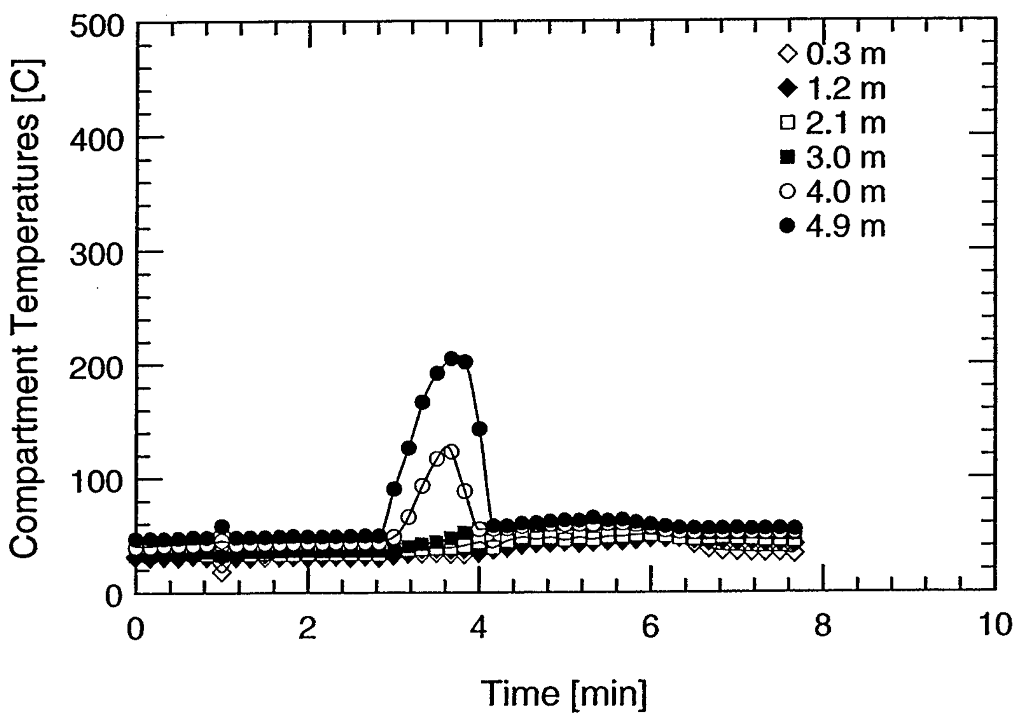


Water Mist System Pressure

Test #13

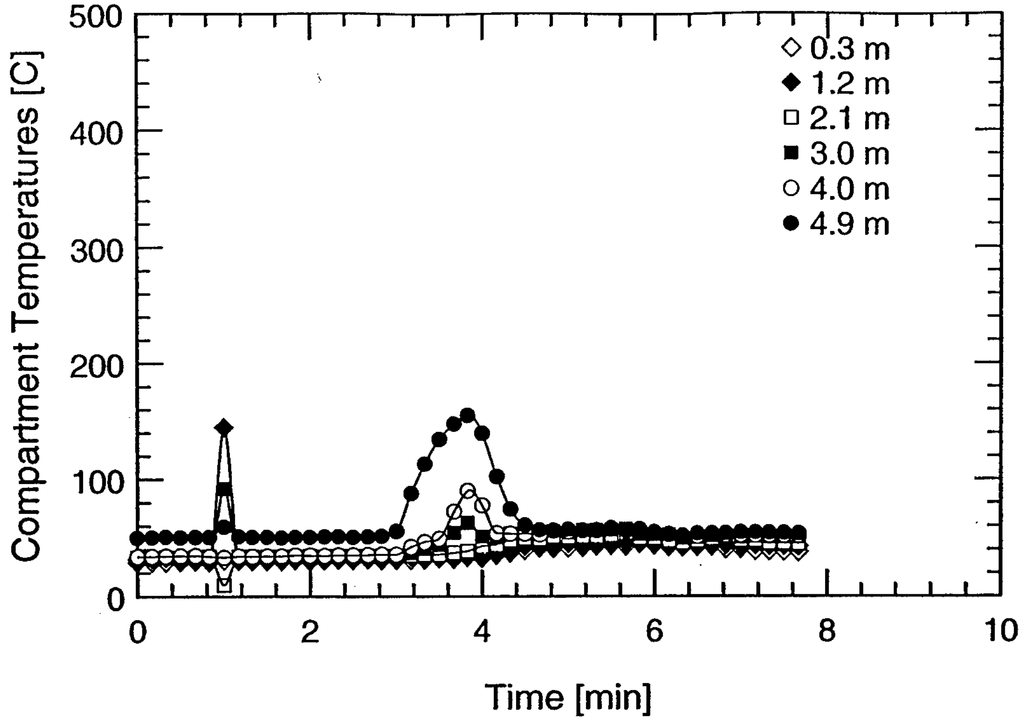


5-22-1

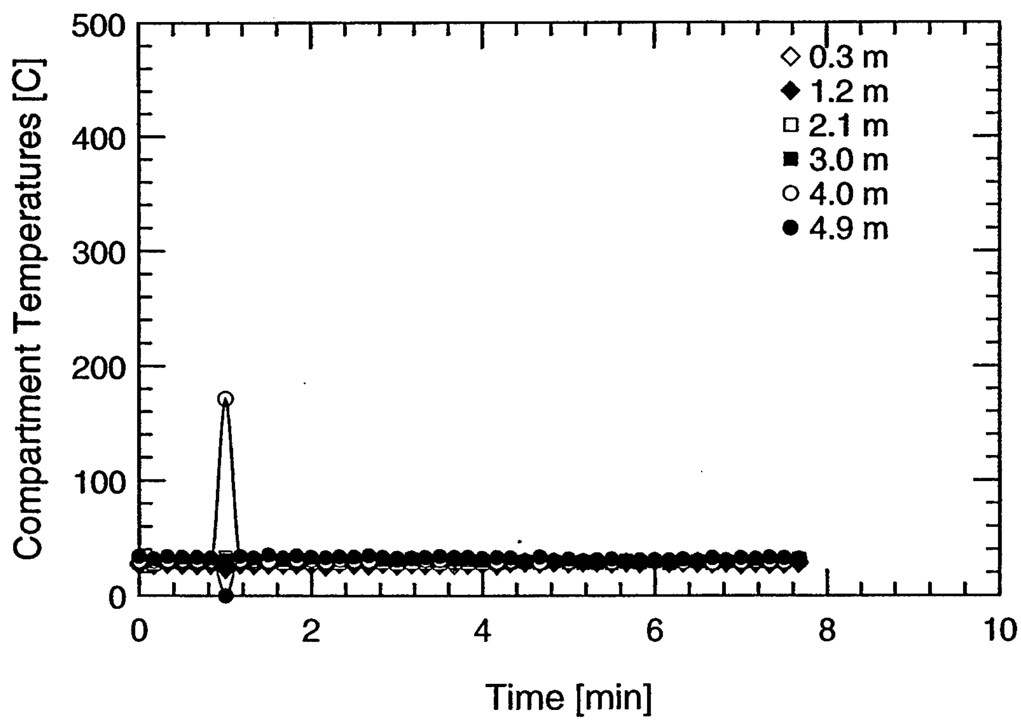


5-27-1

Test #14

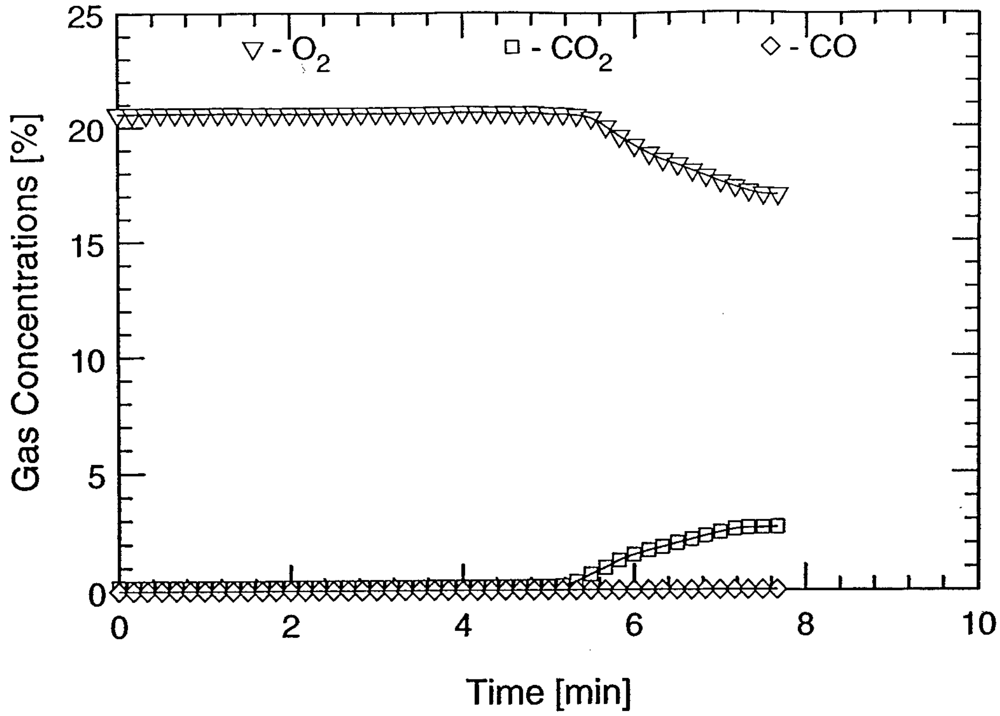


5-27-2

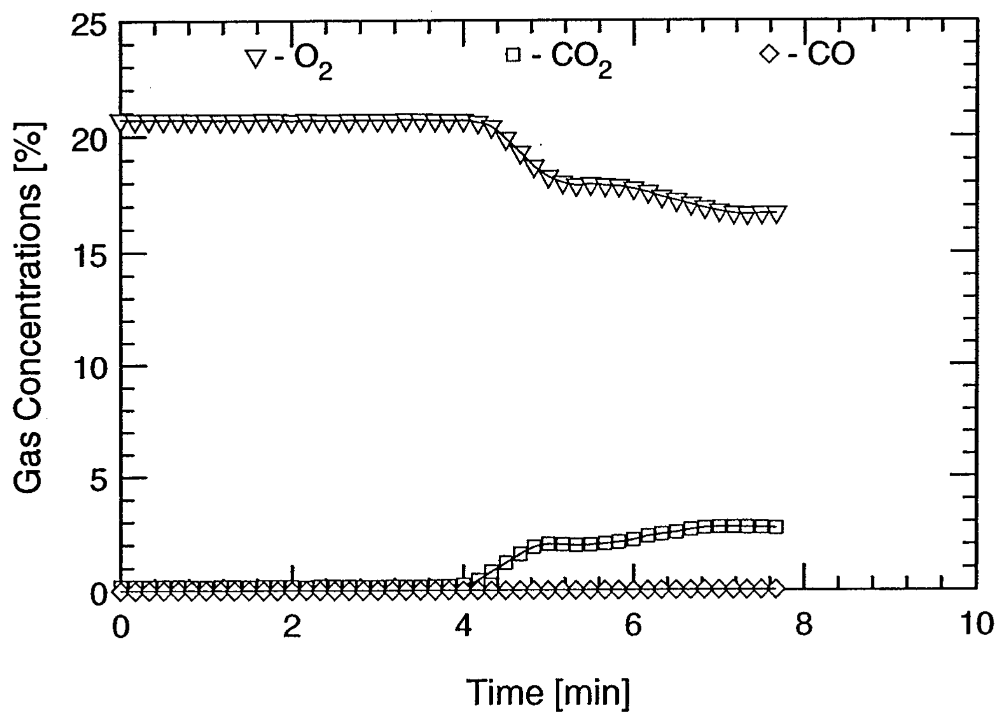


5-35-1

Test #14

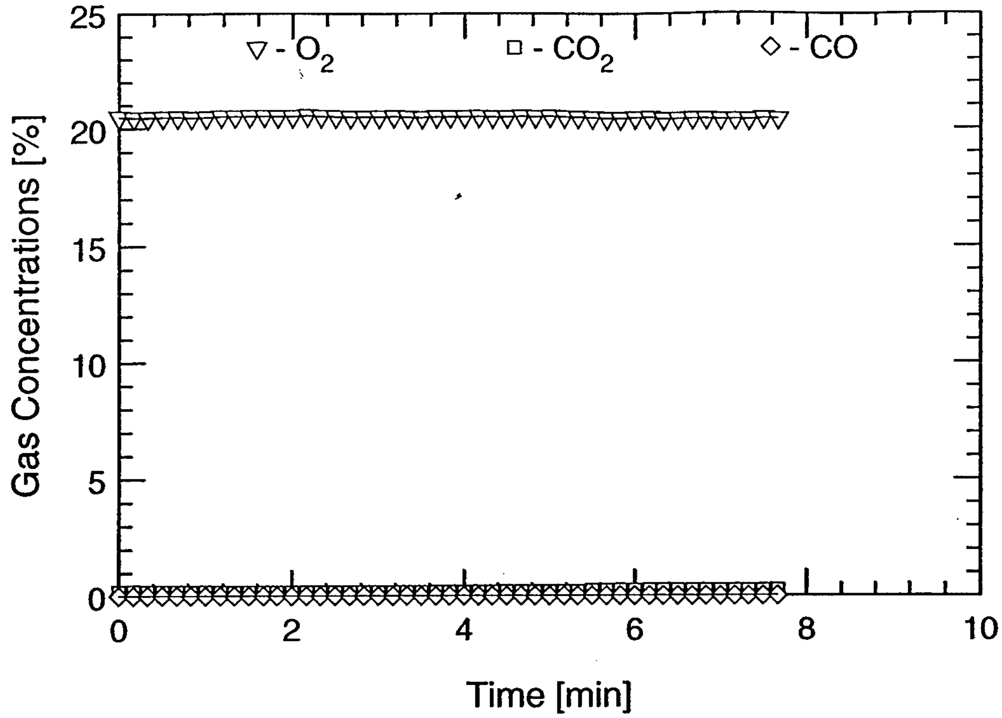


FR 22 - 0.5 m

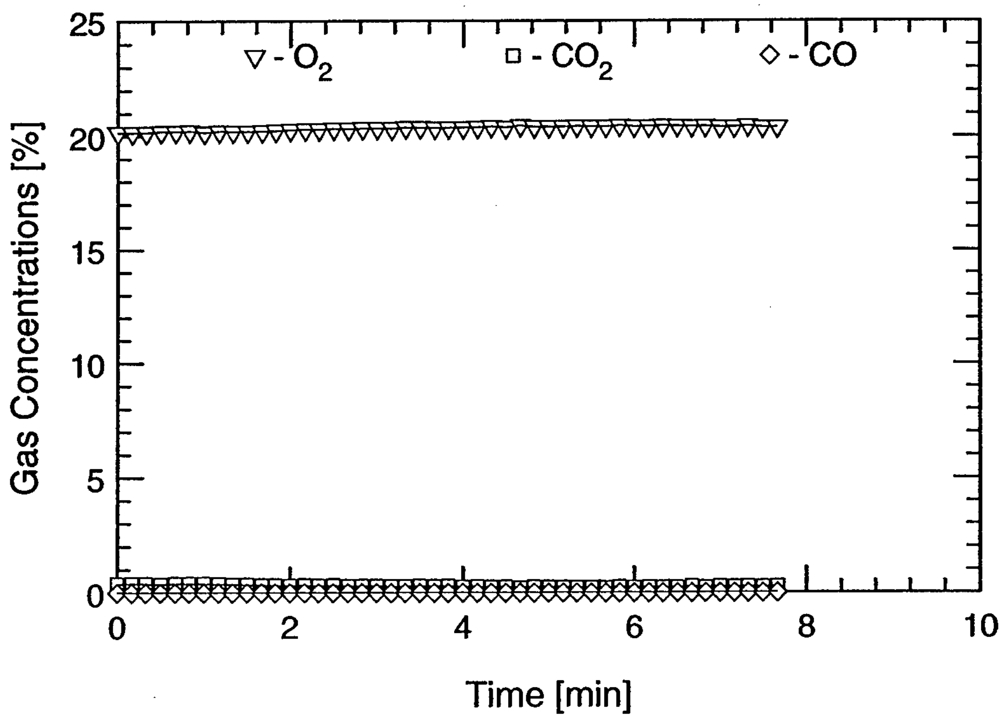


FR 22 - 4.5 m

Test #14

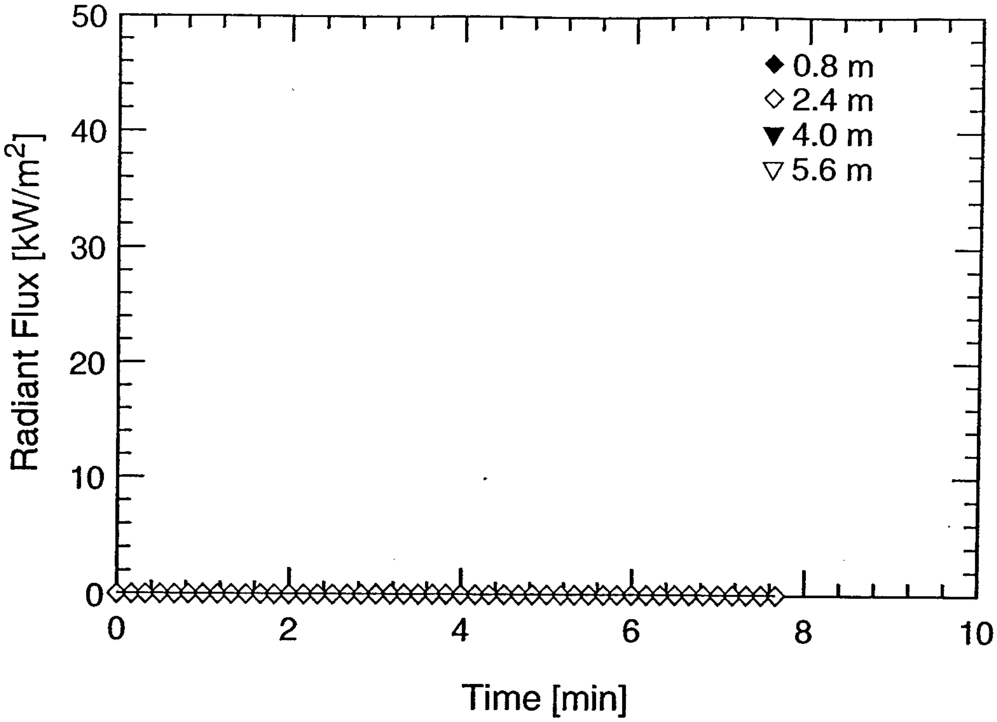


FR 36 - 0.5 m

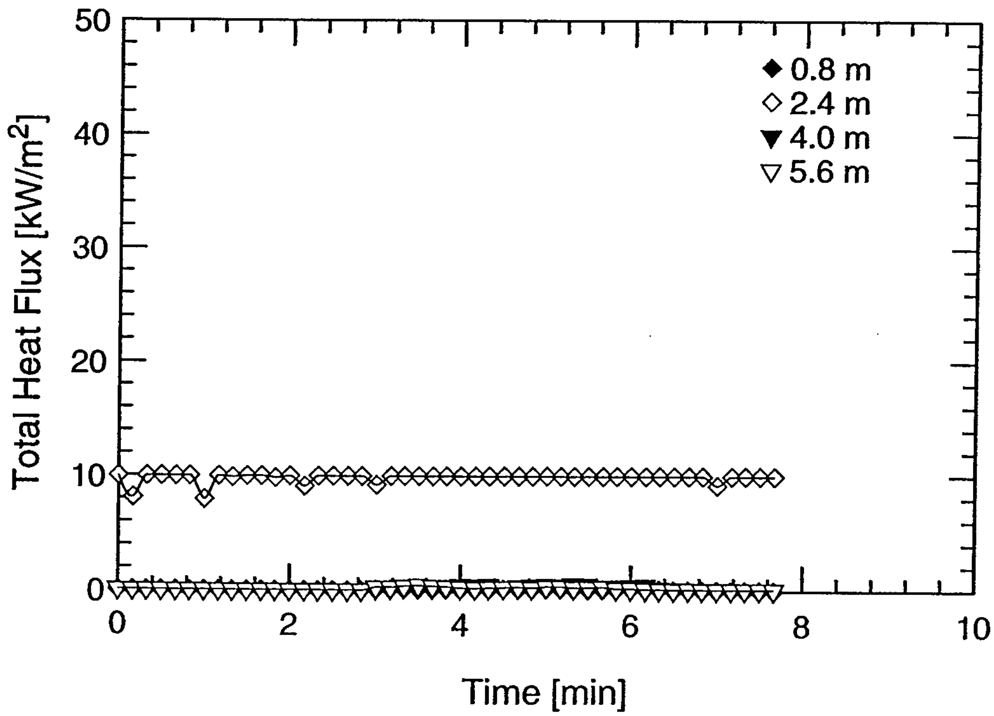


FR 36 - 4.5 m

Test #14

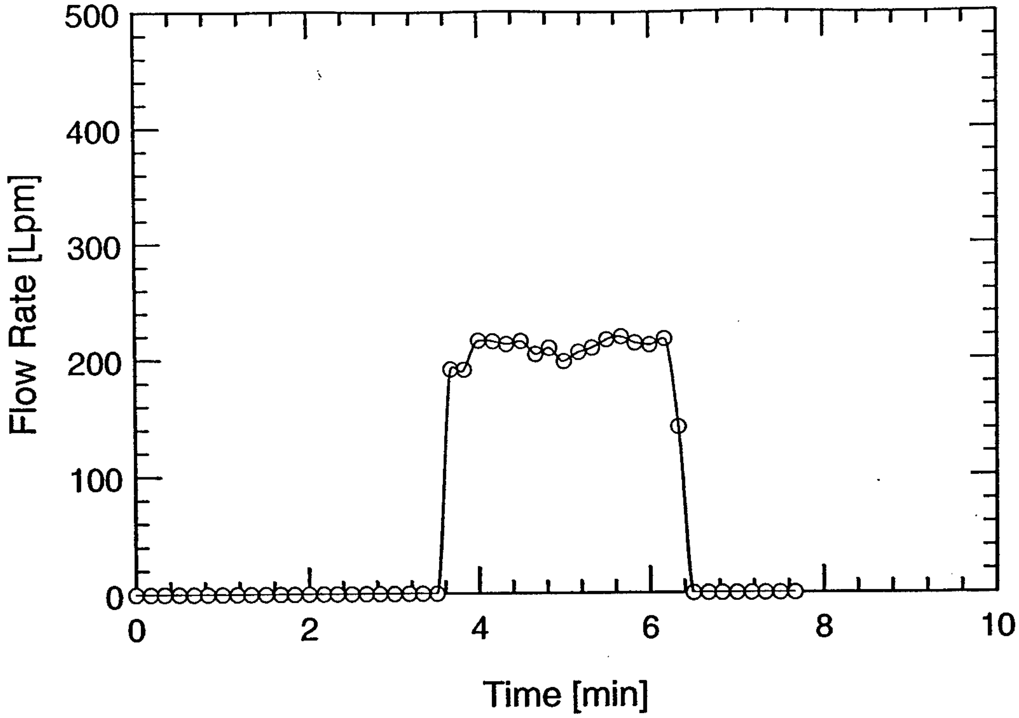


FR 22

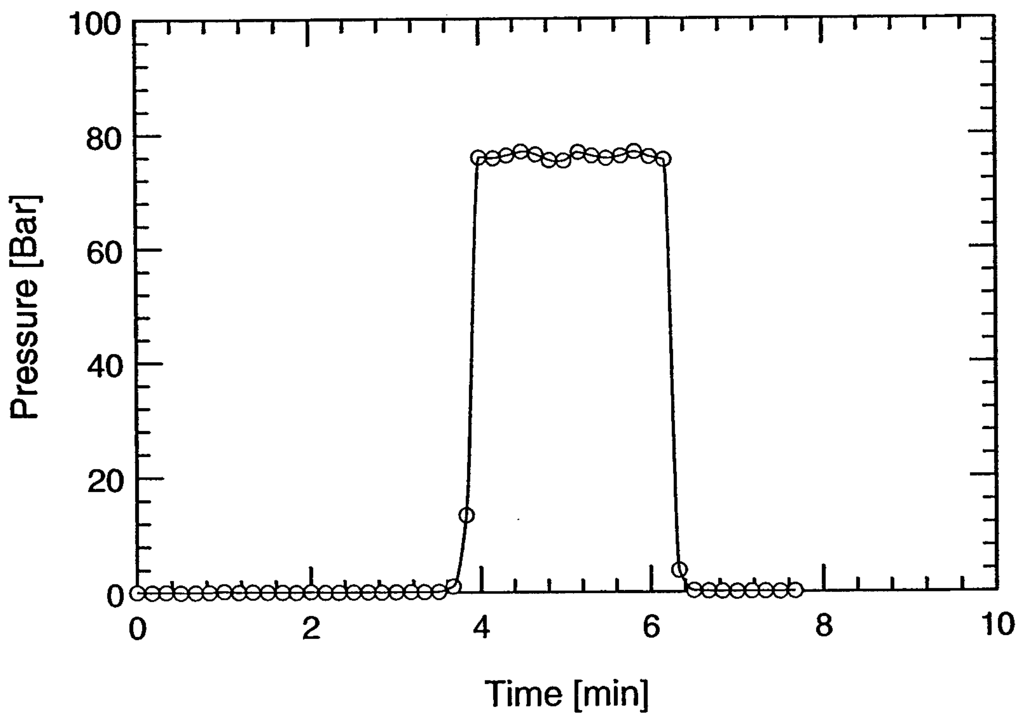


FR 22

Test #14

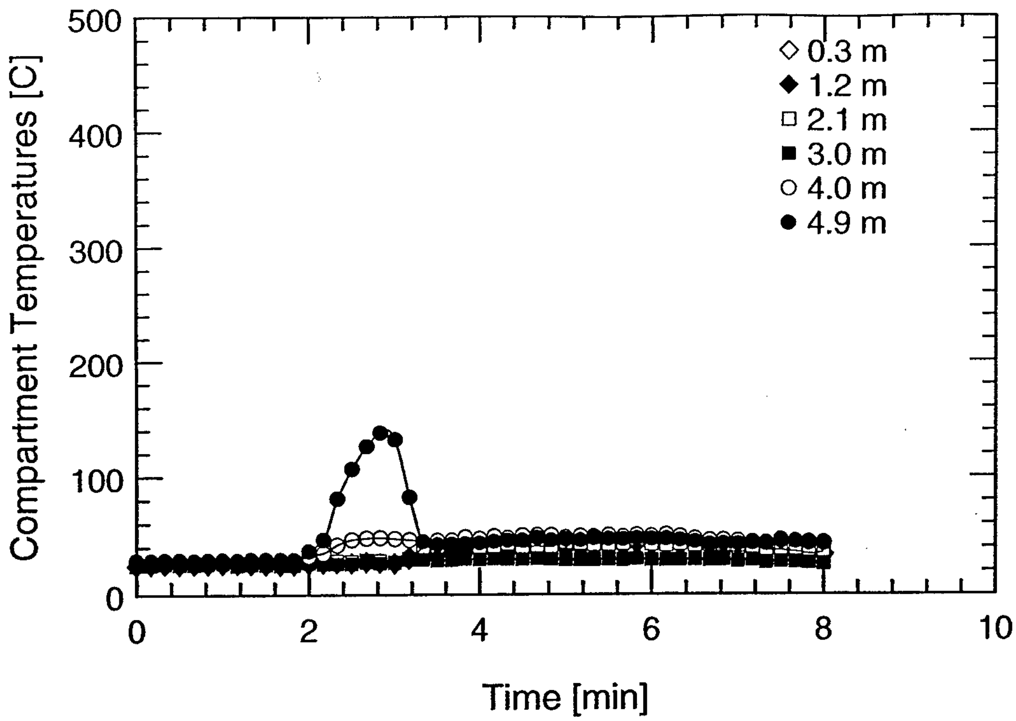


Water Mist System Flow Rate

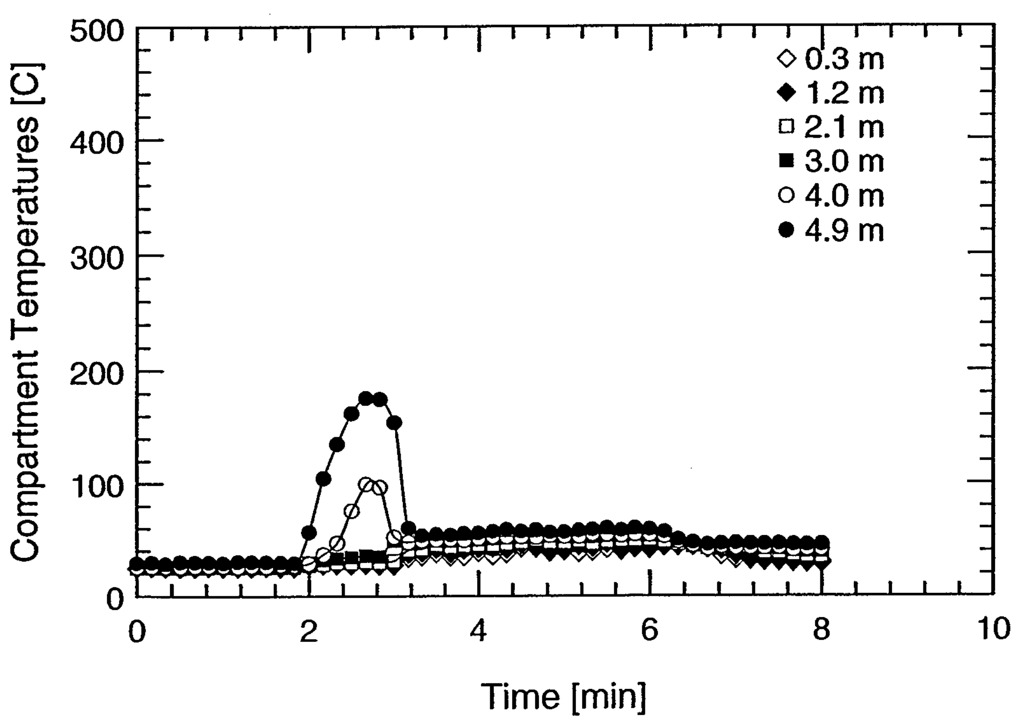


Water Mist System Pressure

Test #14

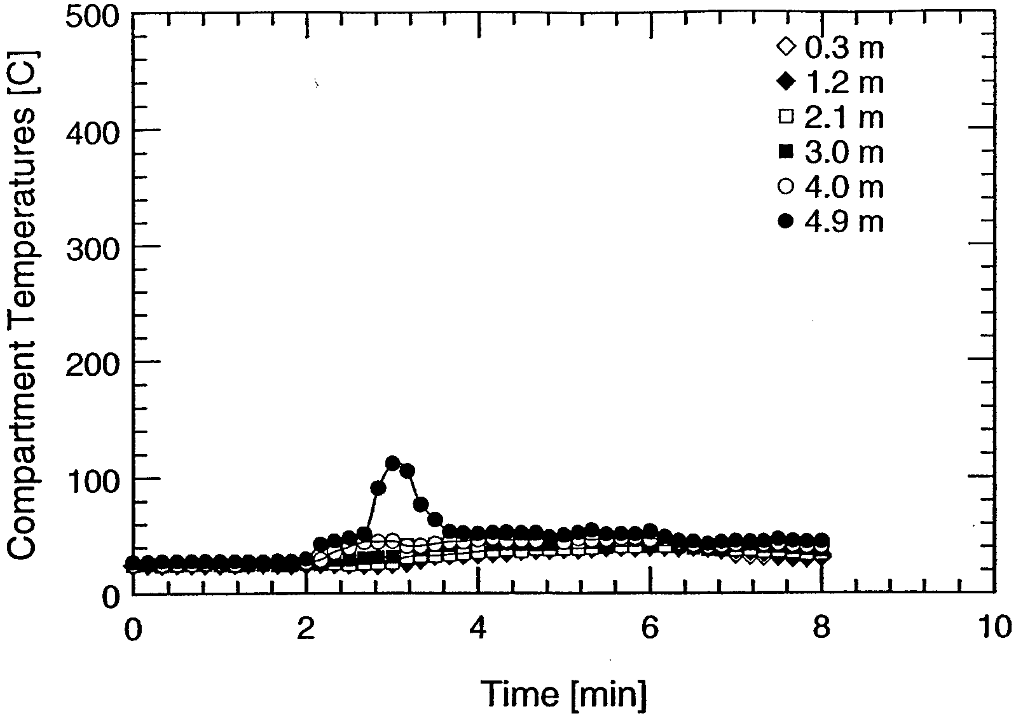


5-22-1

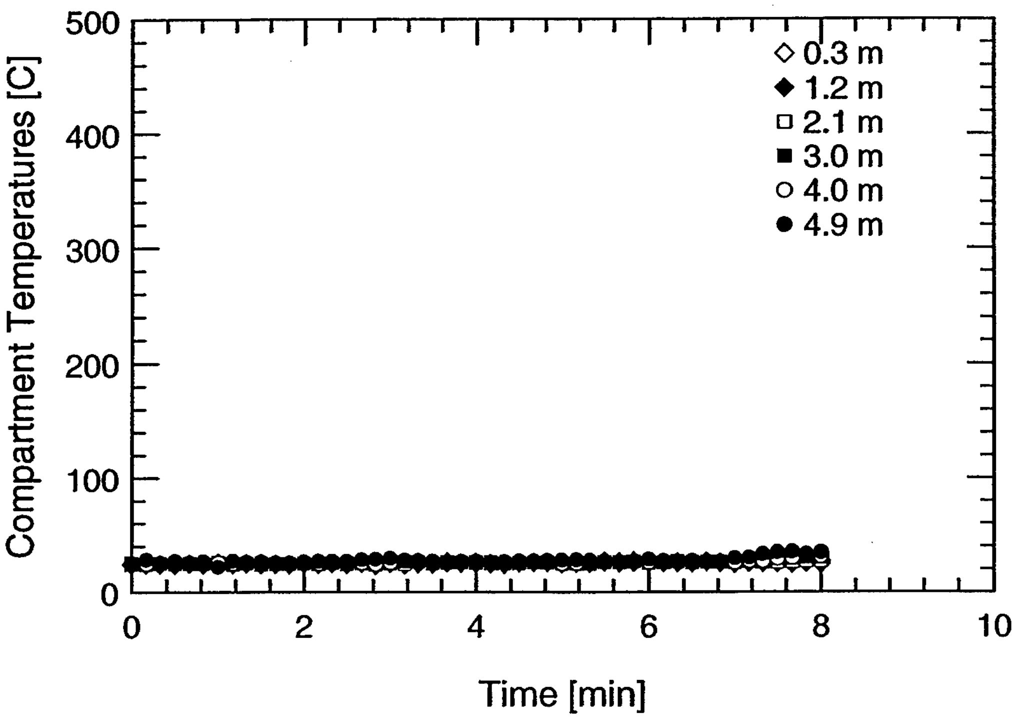


5-27-1

Test #15

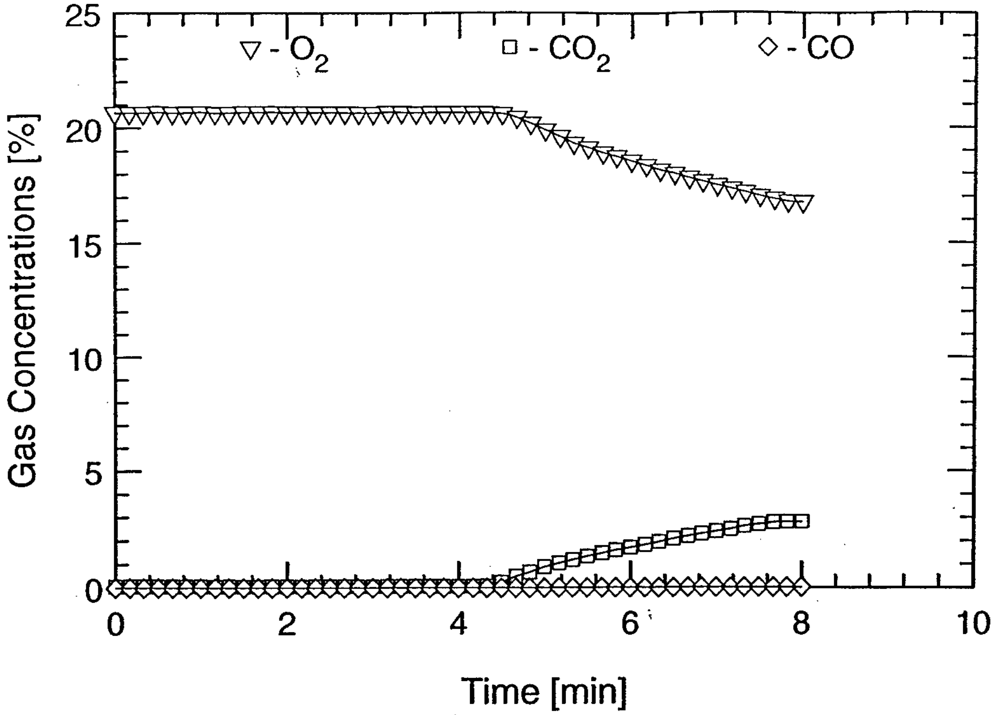


5-27-2

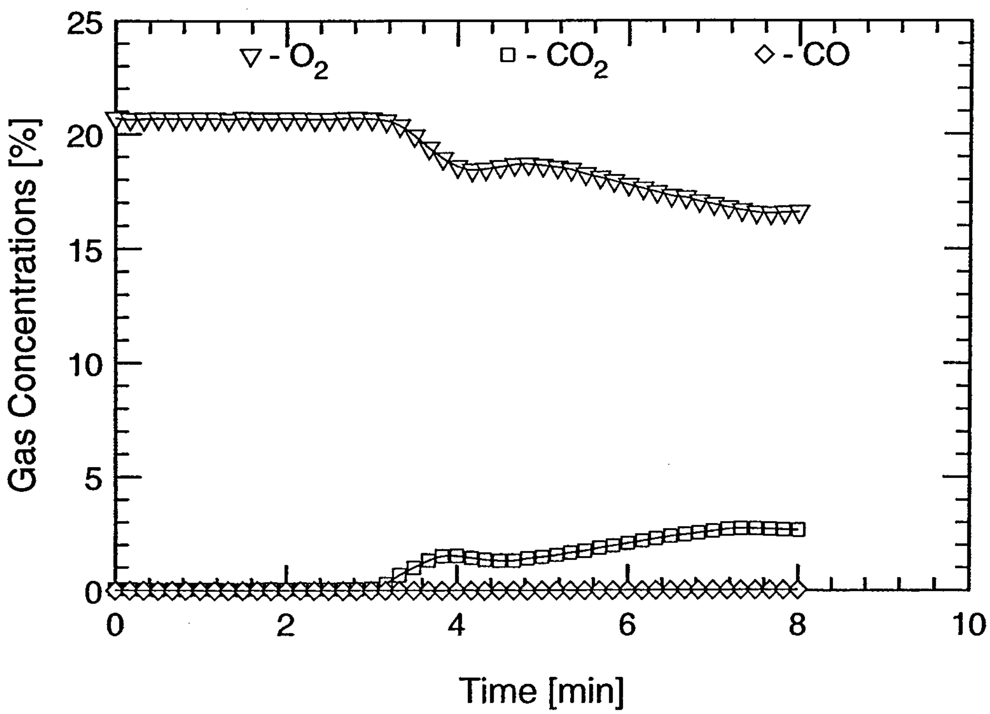


5-35-1

Test #15

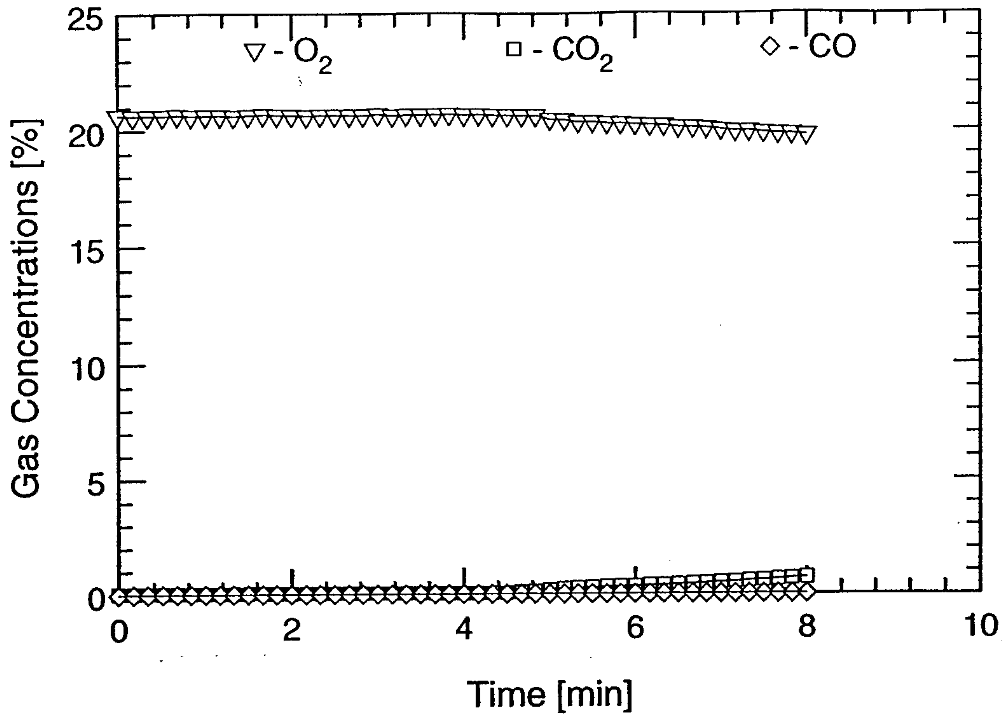


FR 22 - 0.5 m

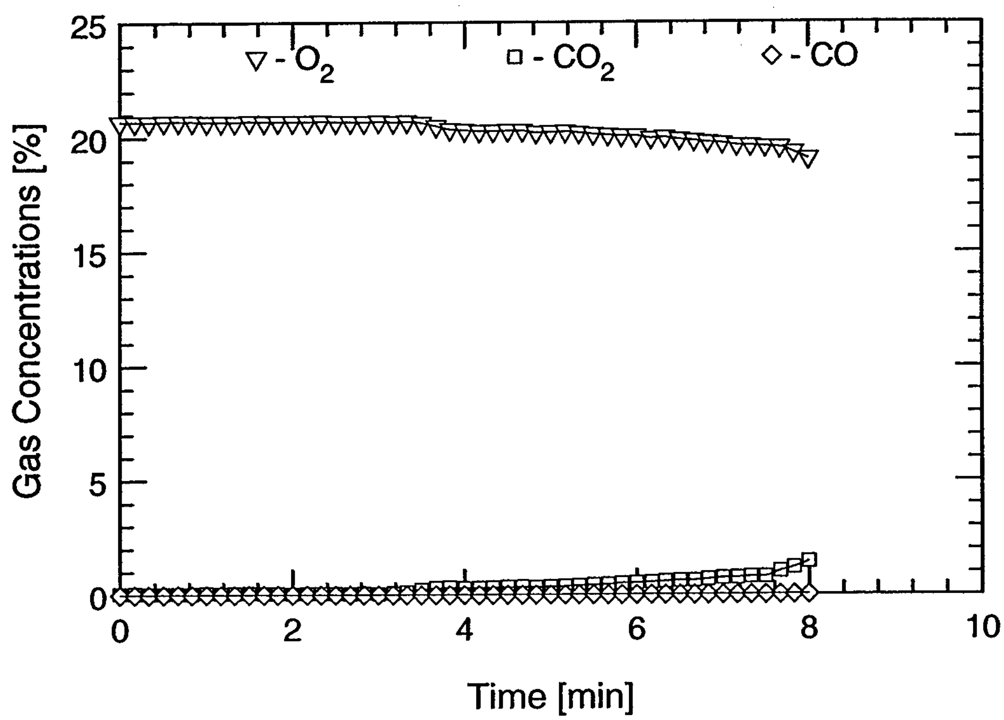


FR 22 - 4.5 m

Test #15

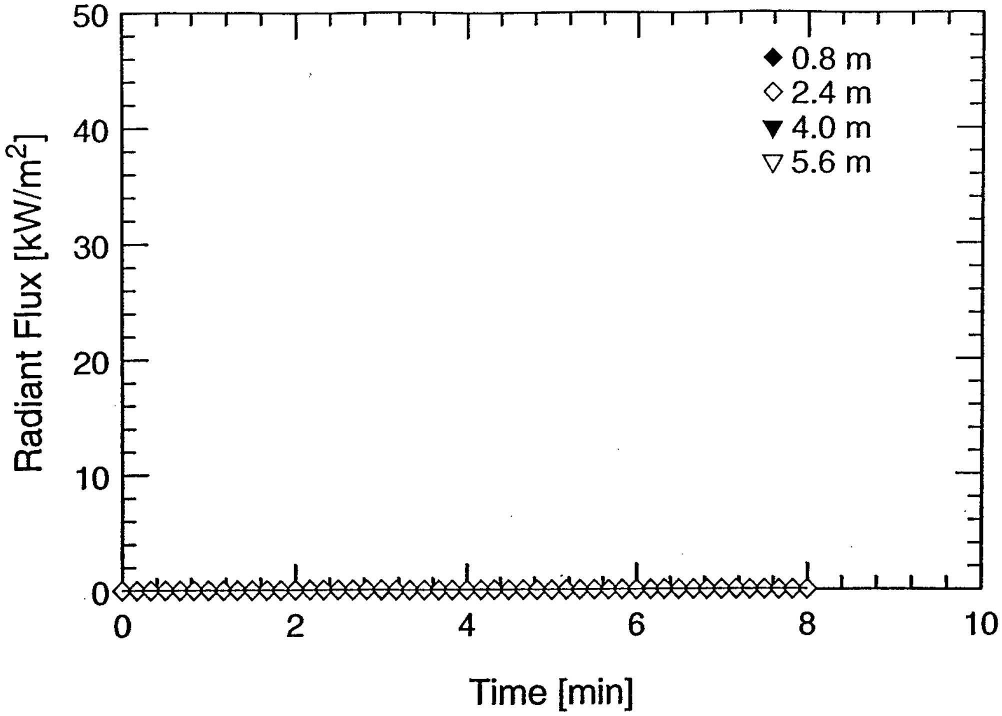


FR 36 - 0.5 m

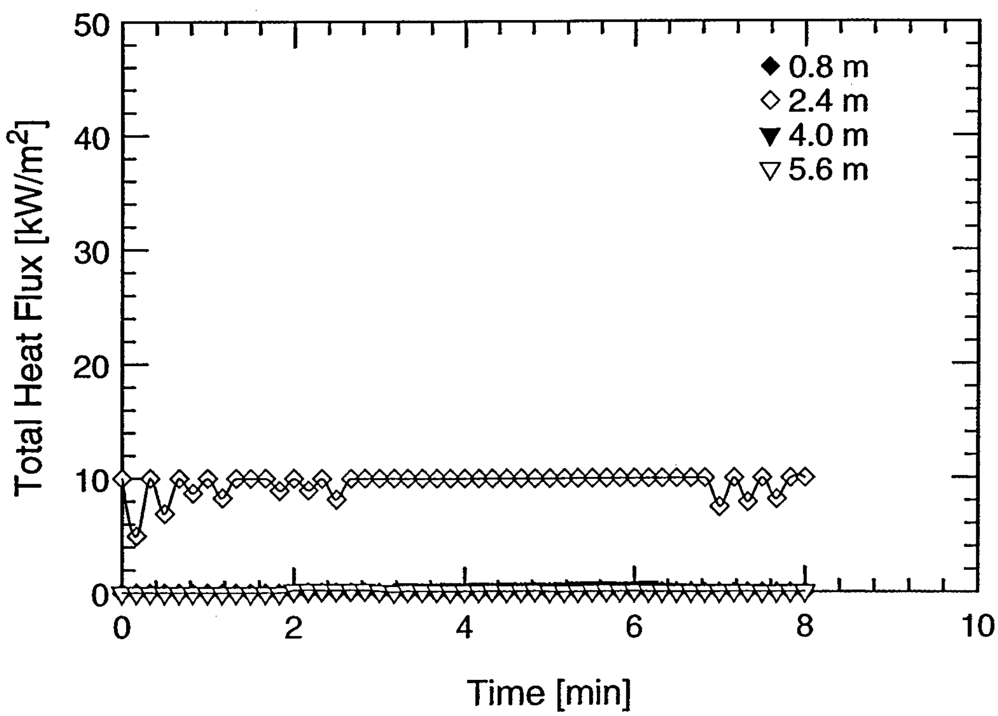


FR 36 - 4.5 m

Test #15

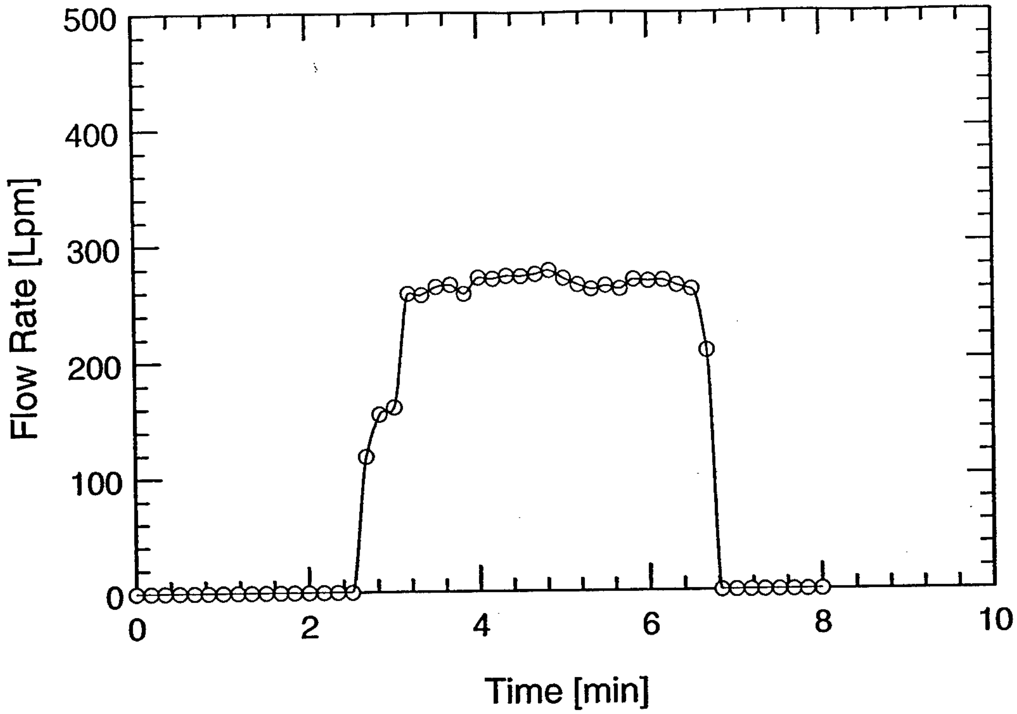


FR 22

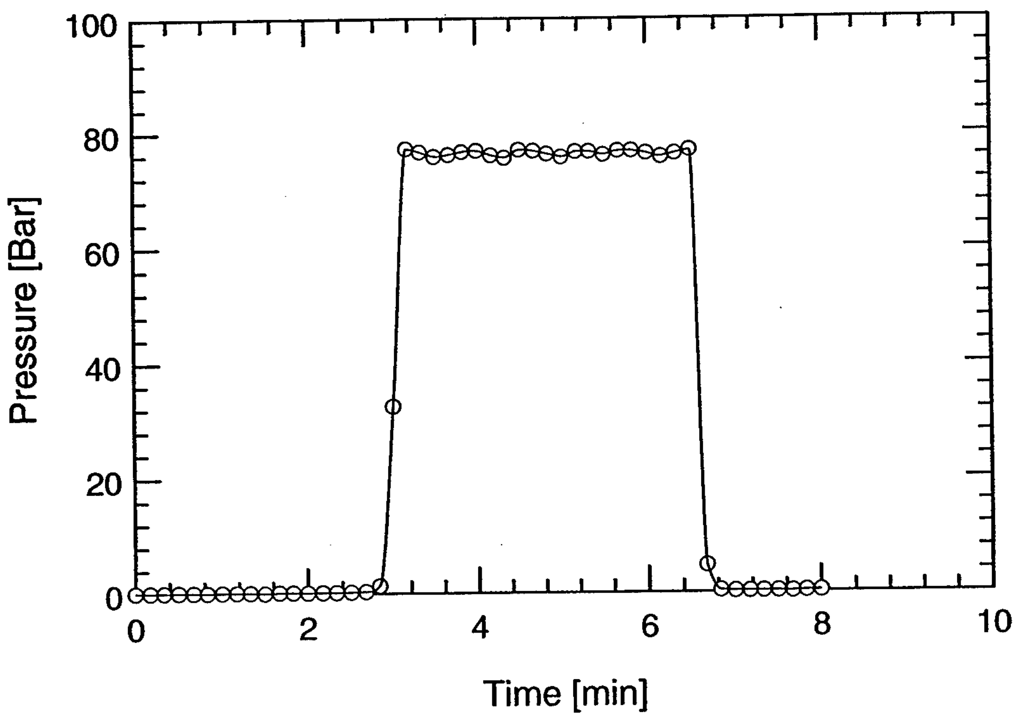


FR 22

Test #15

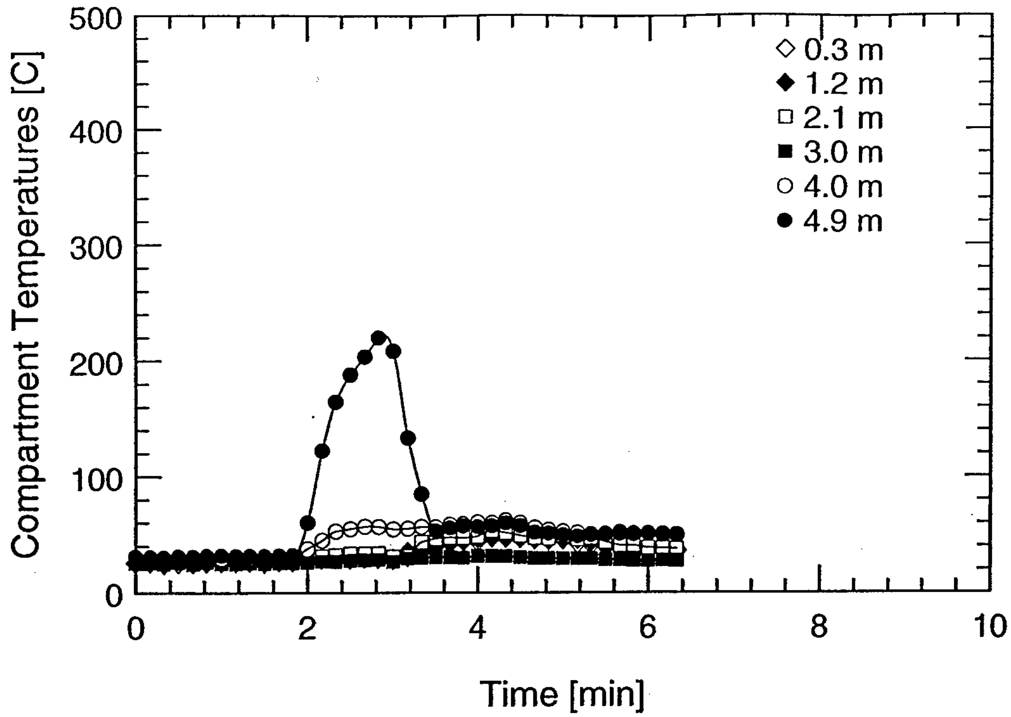


Water Mist System Flow Rate

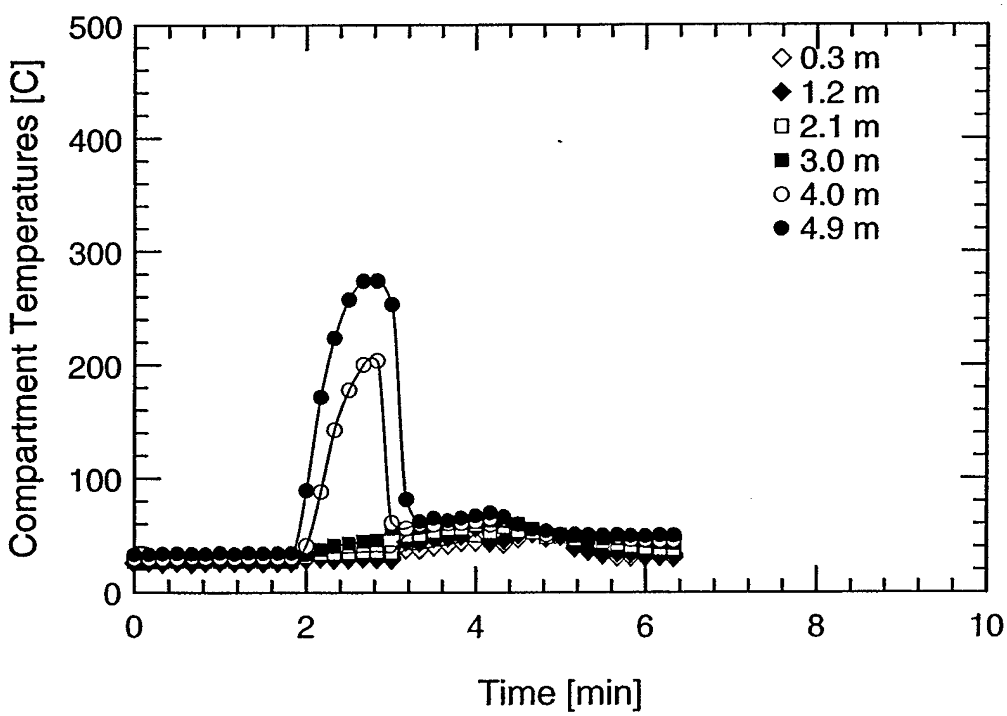


Water Mist System Pressure

Test #15

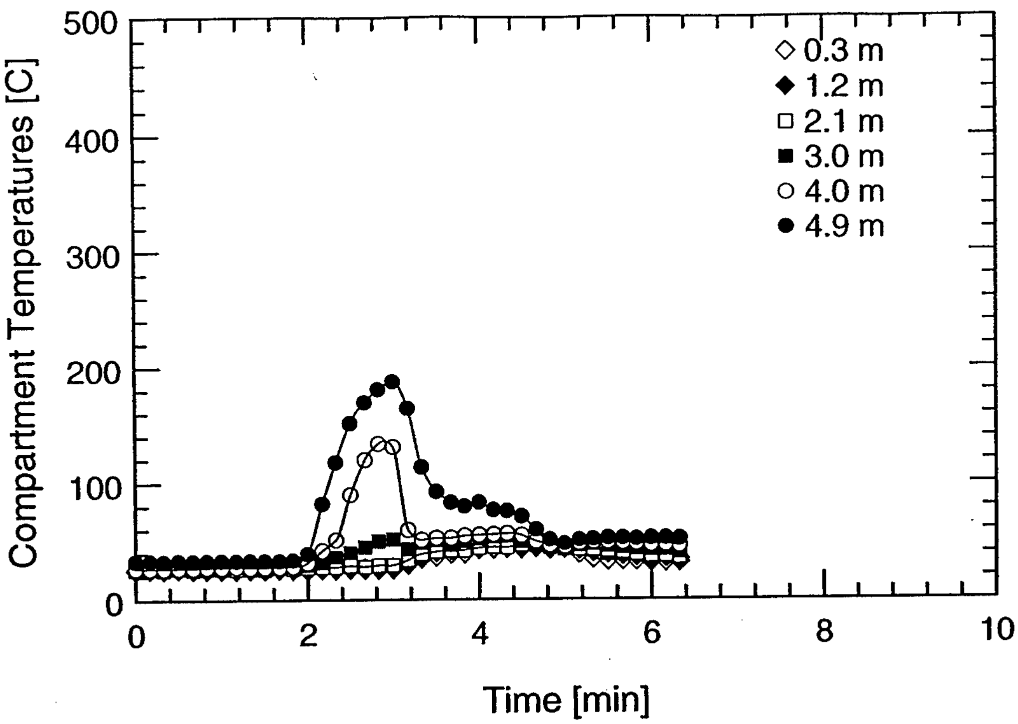


5-22-1

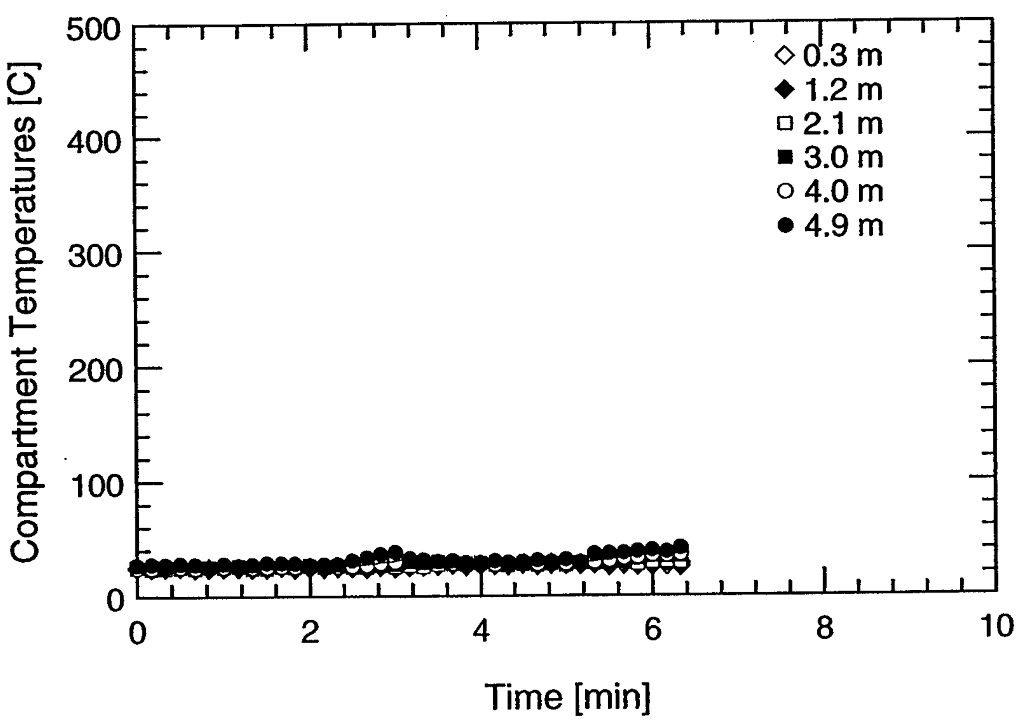


5-27-1

Test #16

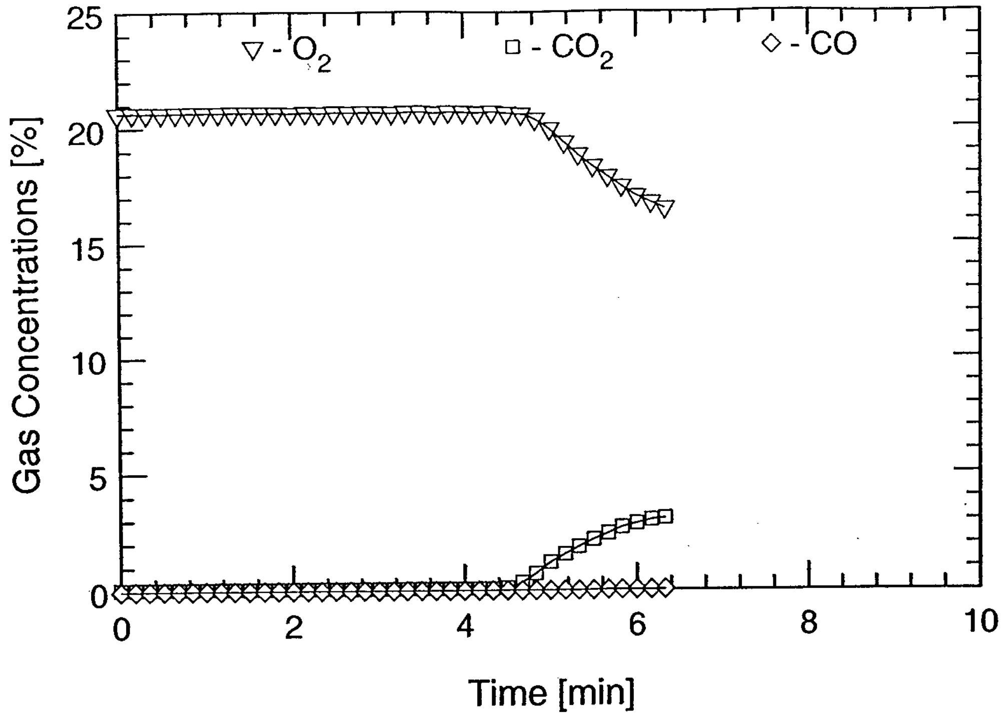


5-27-2

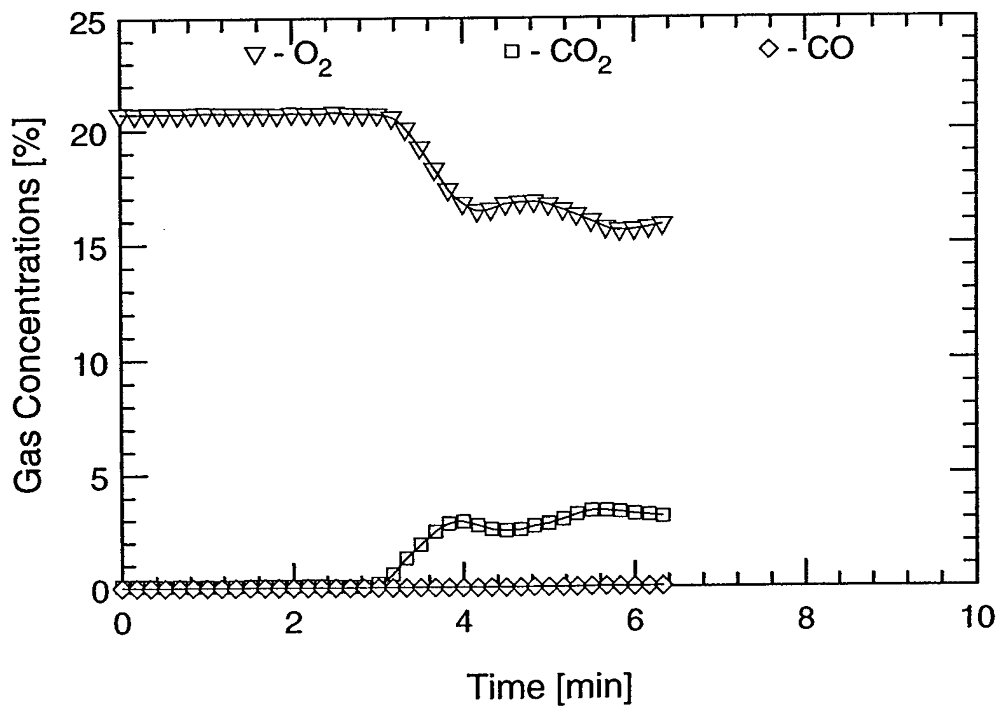


5-35-1

Test #16

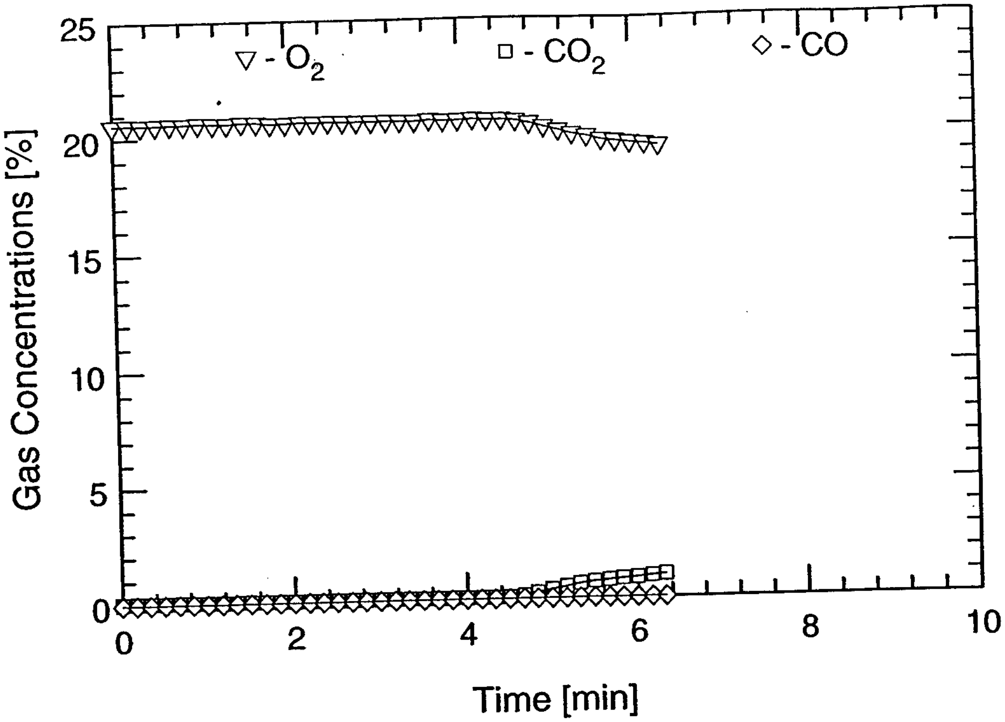


FR 22 - 0.5 m

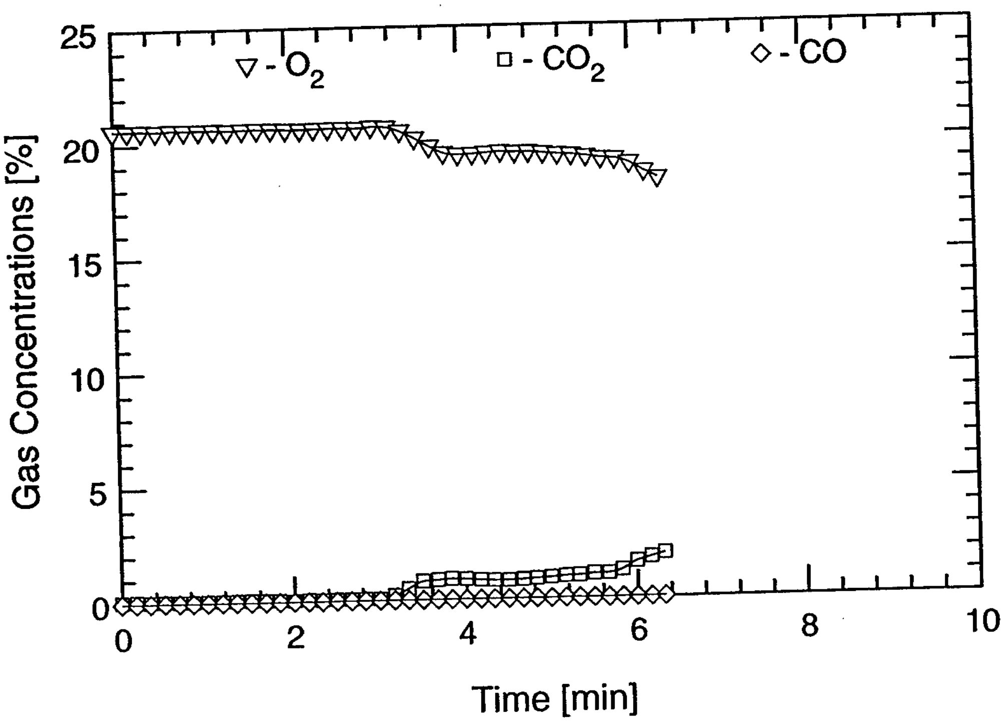


FR 22 - 4.5 m

Test #16

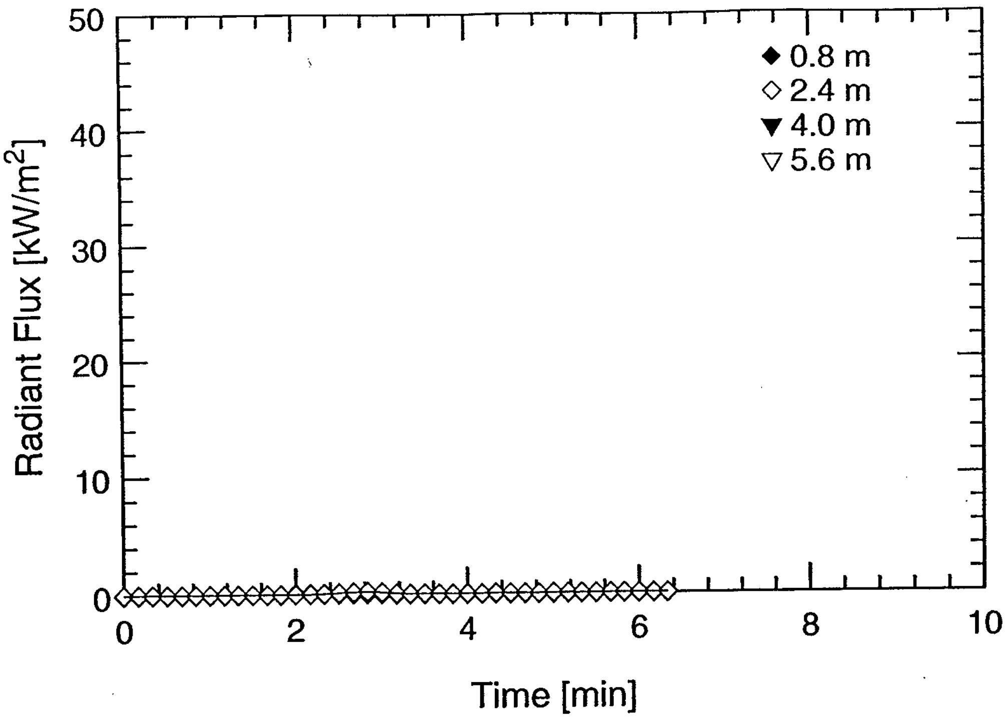


FR 36 - 0.5 m

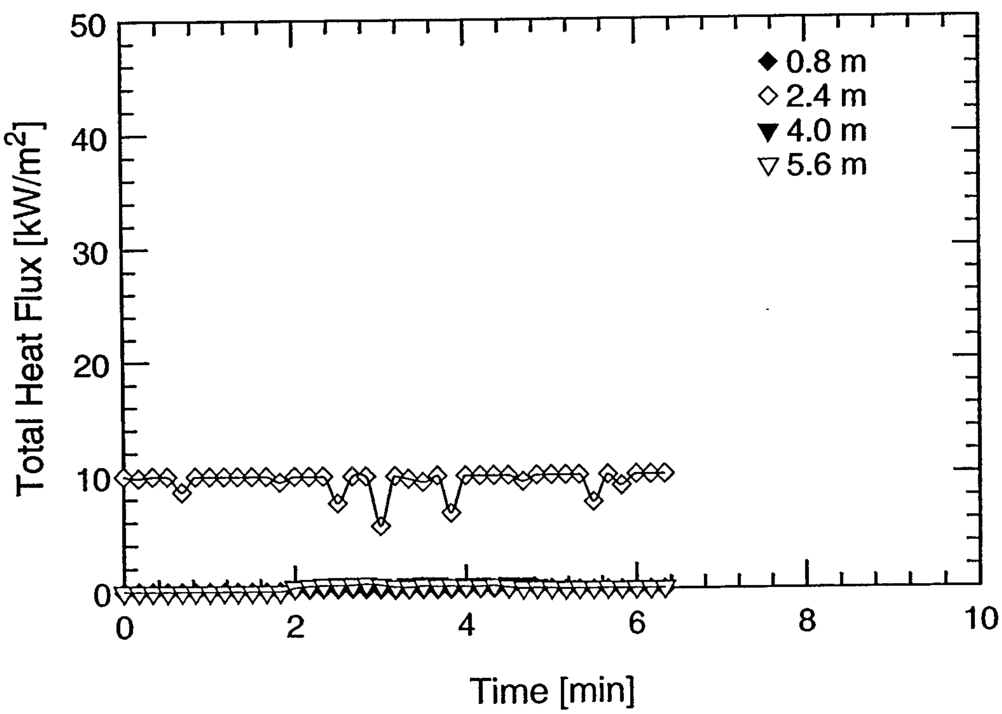


FR 36 - 4.5 m

Test #16

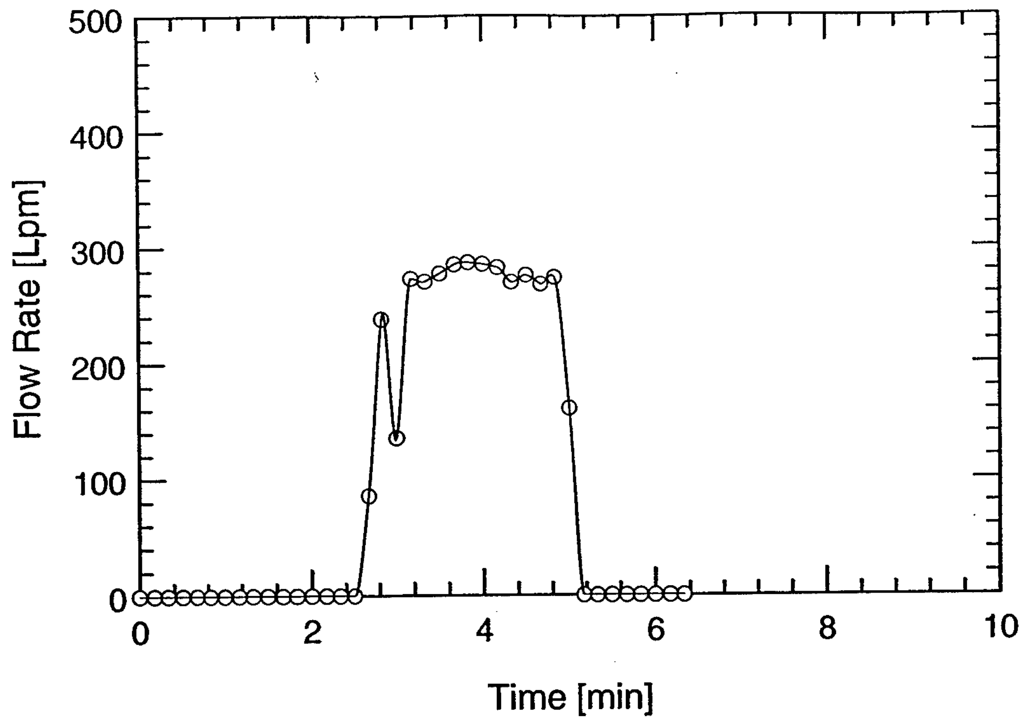


FR 22

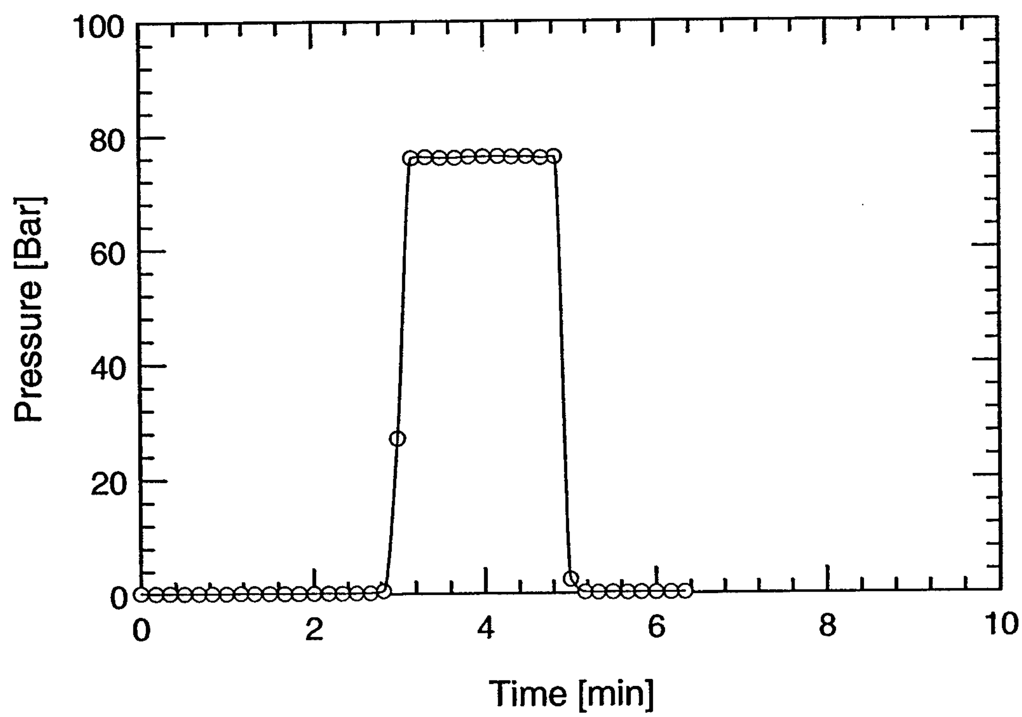


FR 22

Test #16

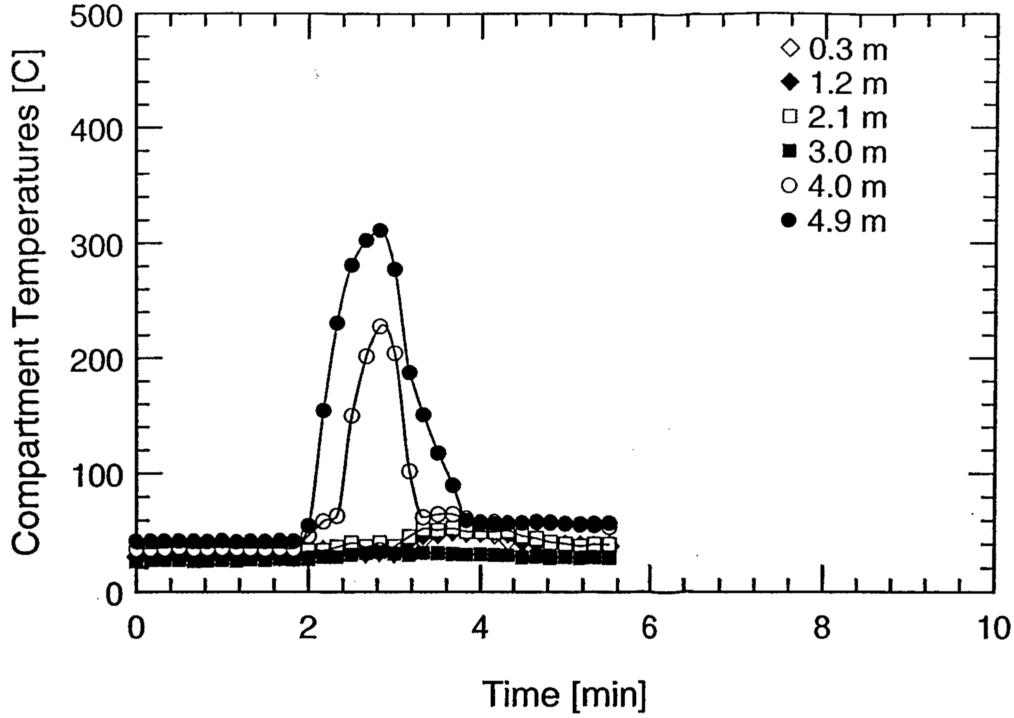


Water Mist System Flow Rate

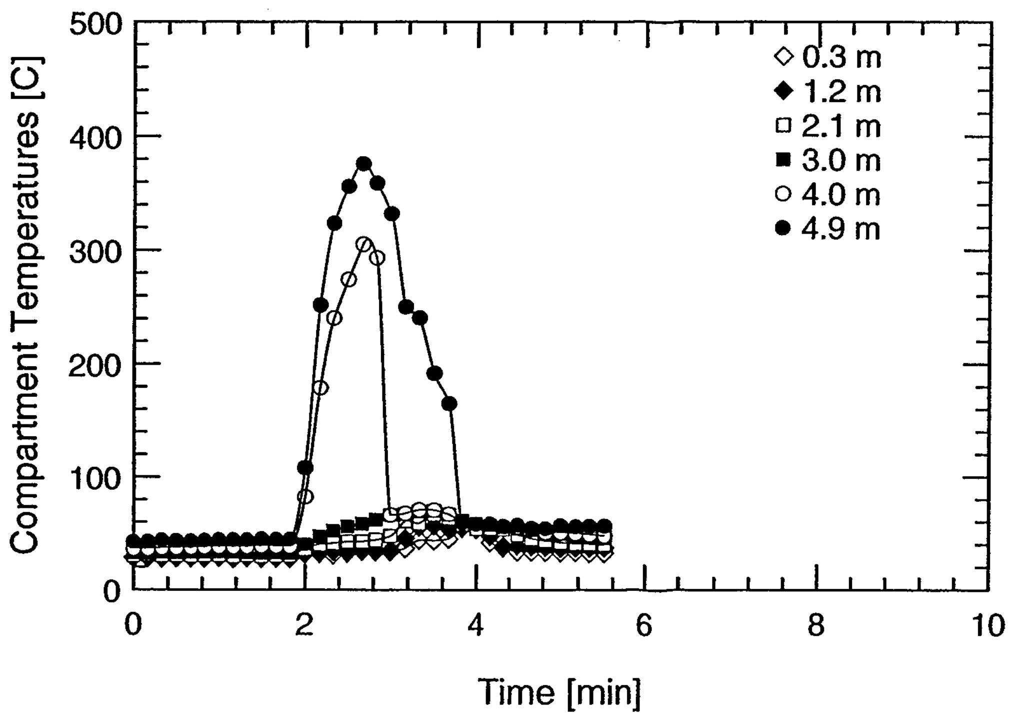


Water Mist System Pressure

Test #16

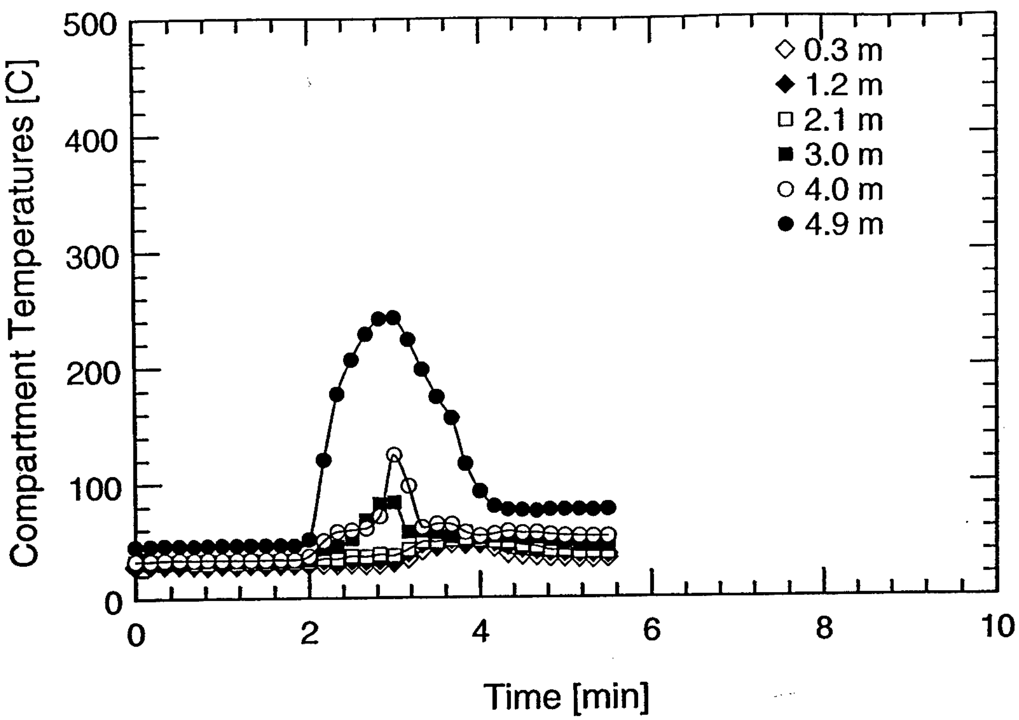


5-22-1

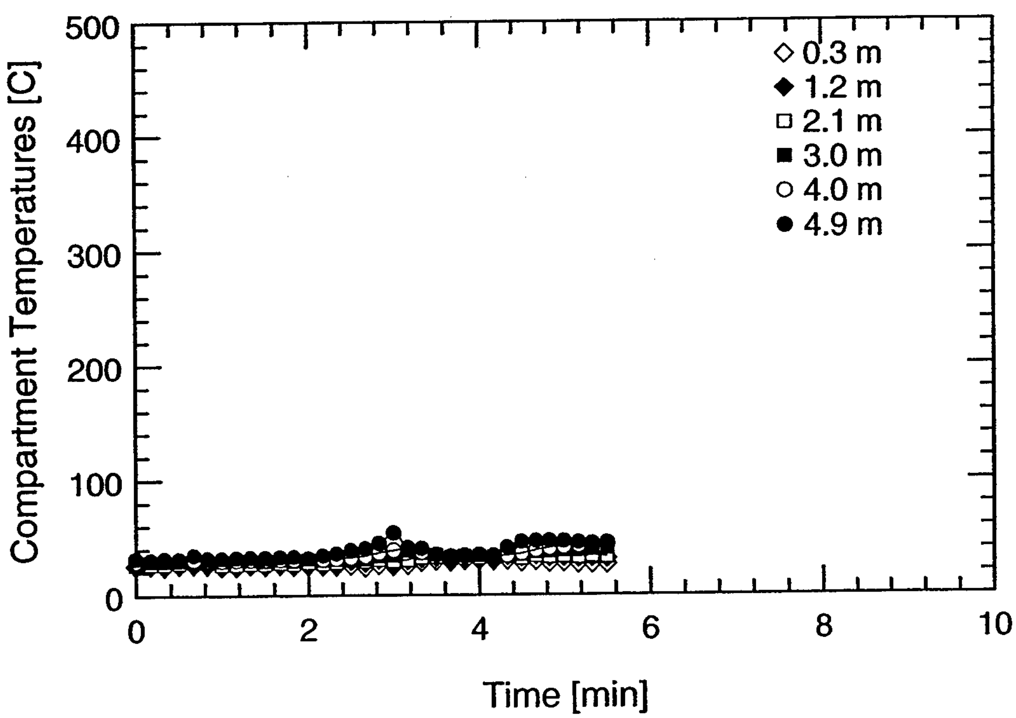


5-27-1

Test #17

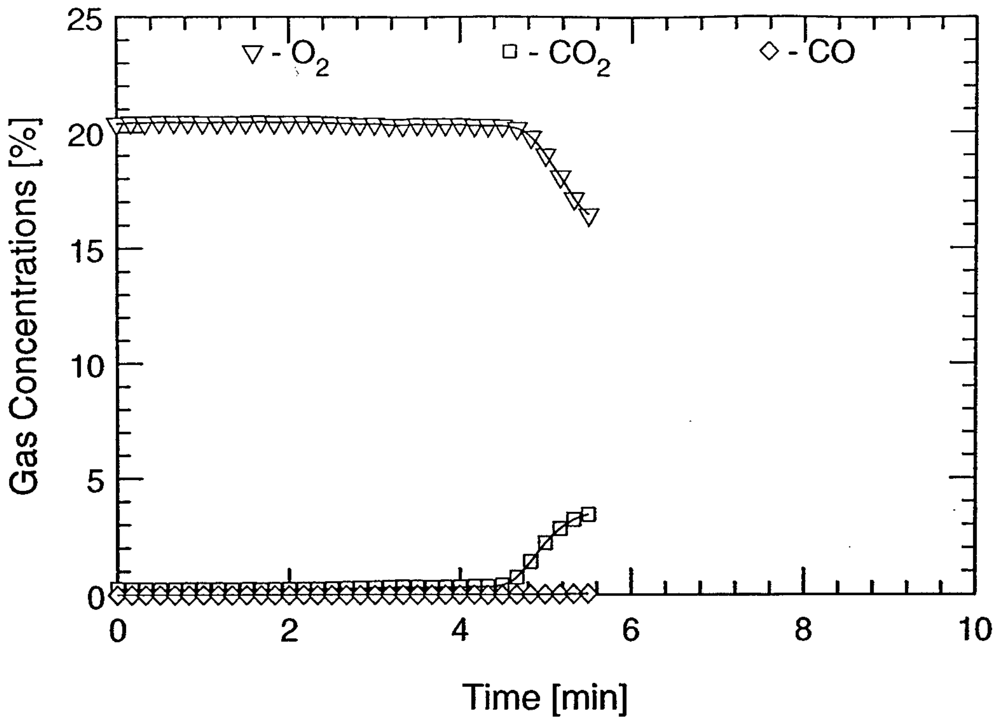


5-27-2

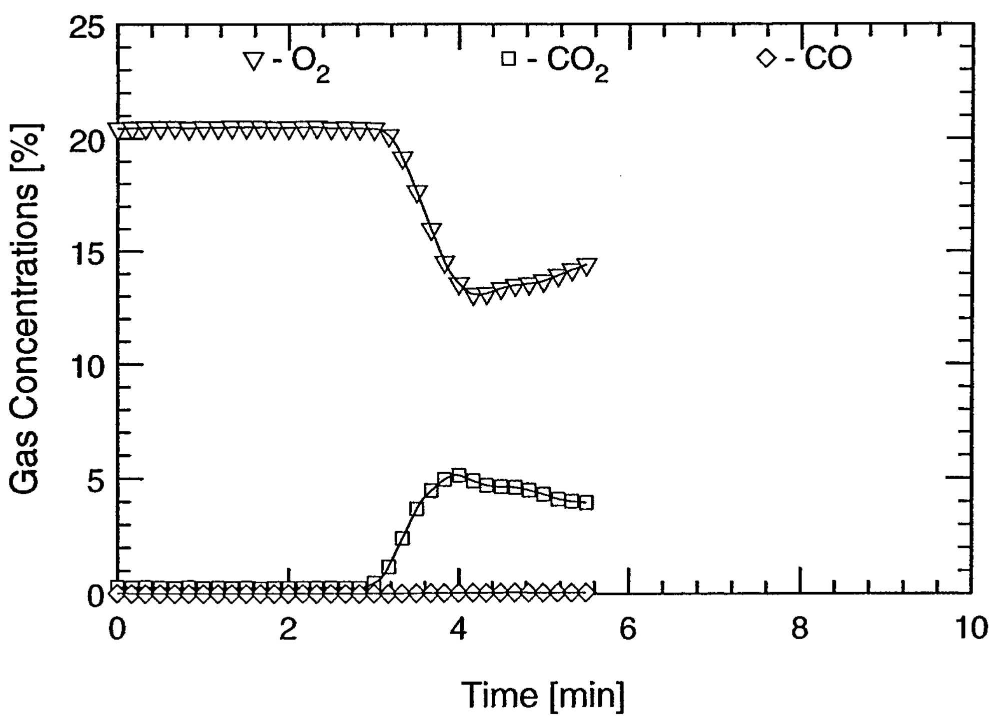


5-35-1

Test #17

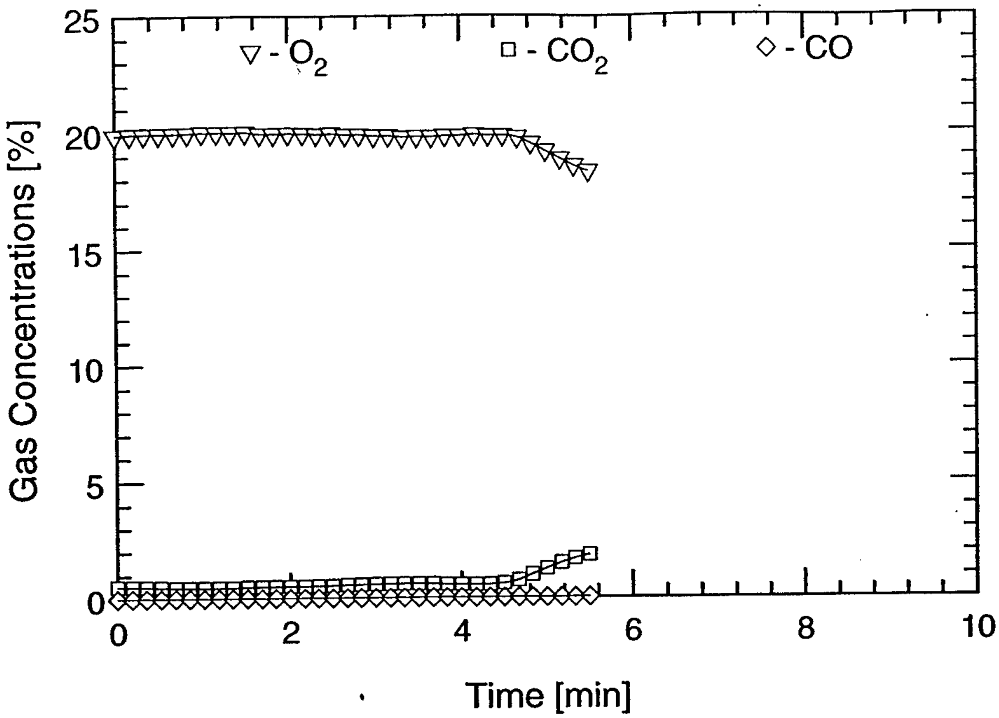


FR 22 - 0.5 m

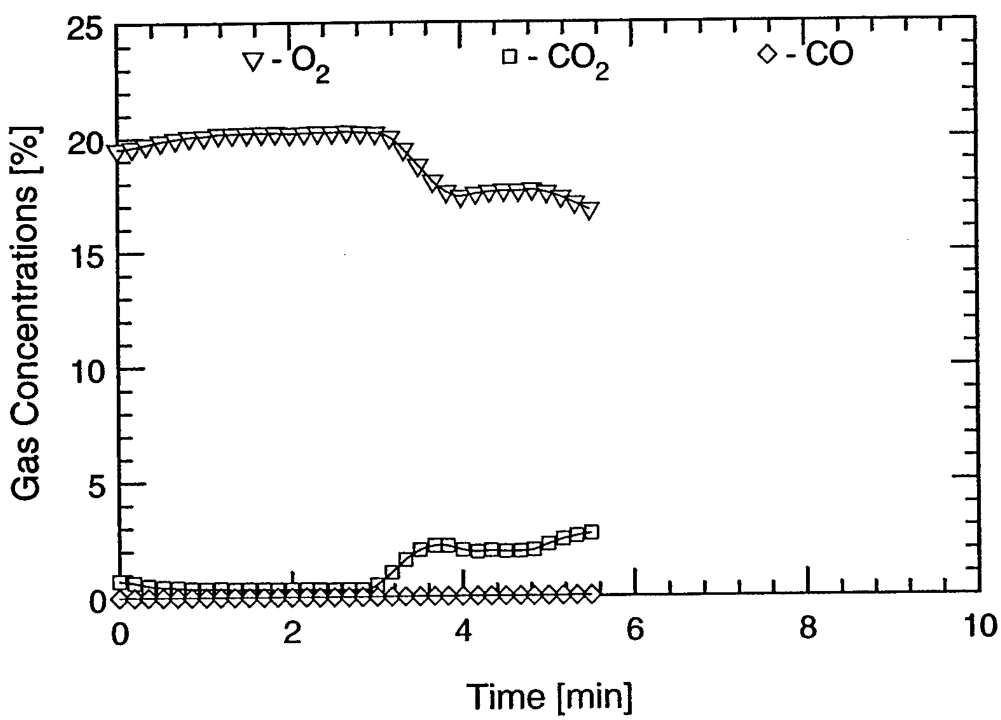


FR 22 - 4.5 m

Test #17

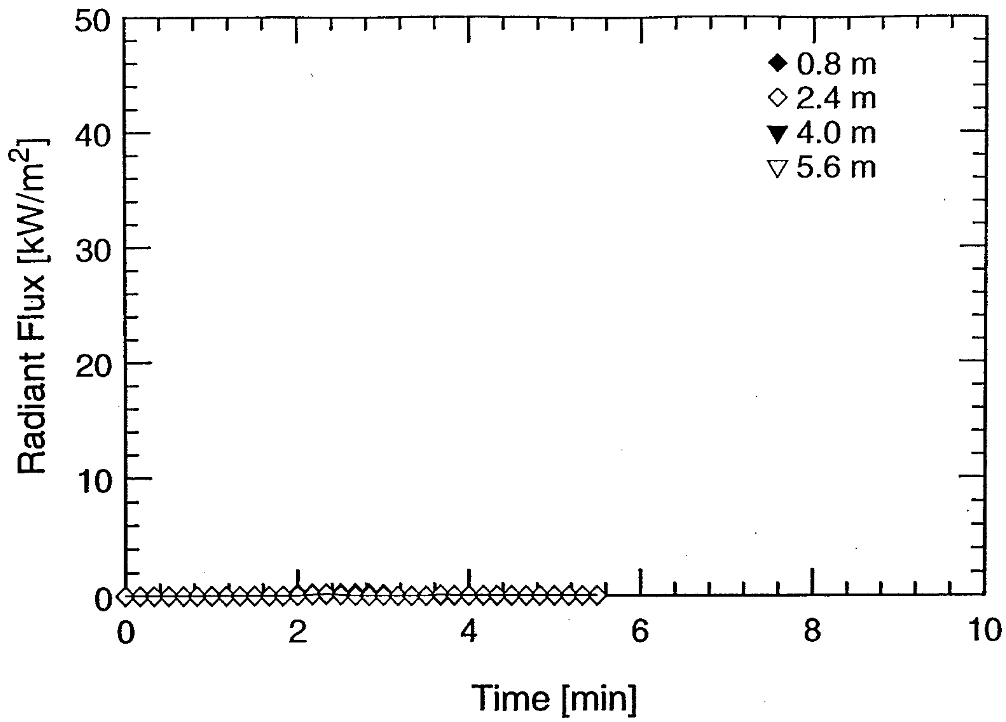


FR 36 - 0.5 m

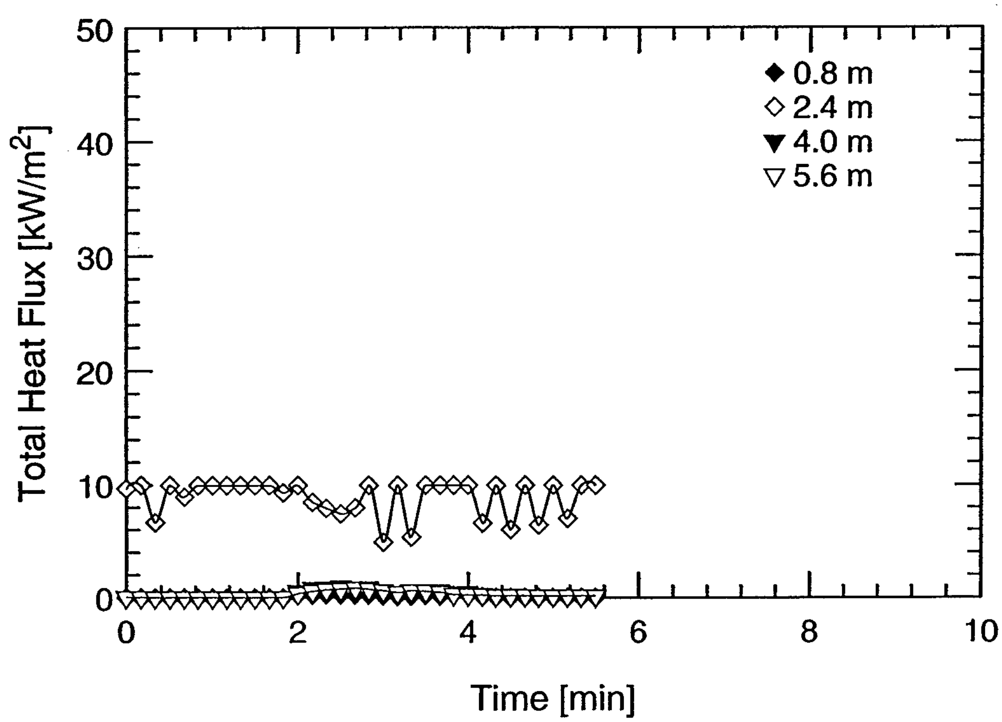


FR 36 - 4.5 m

Test #17

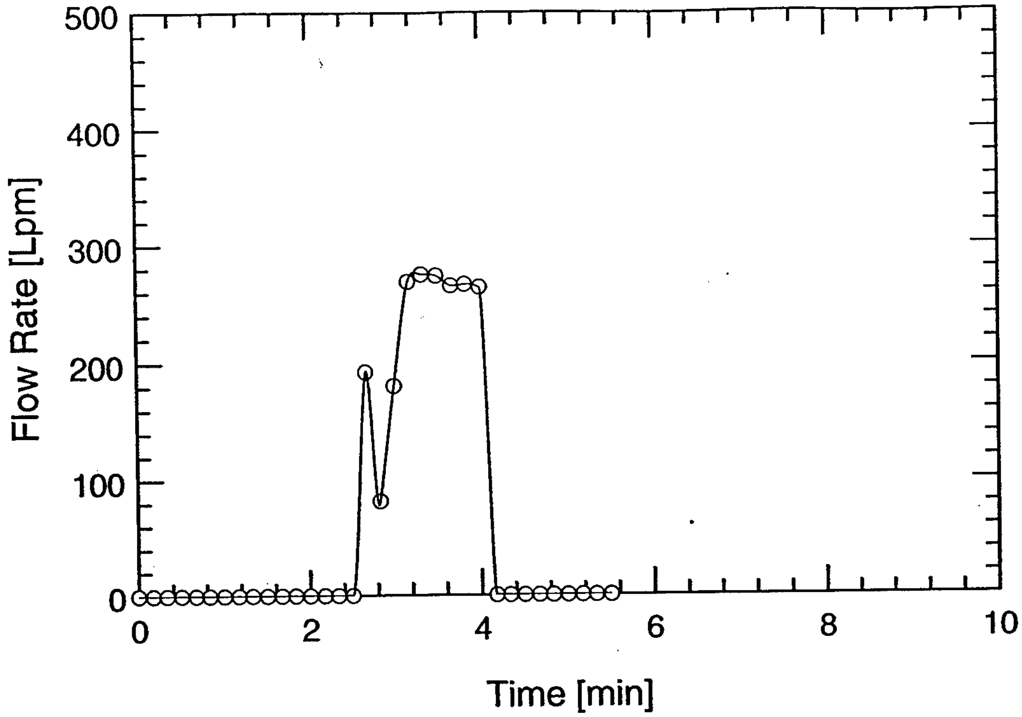


FR 22

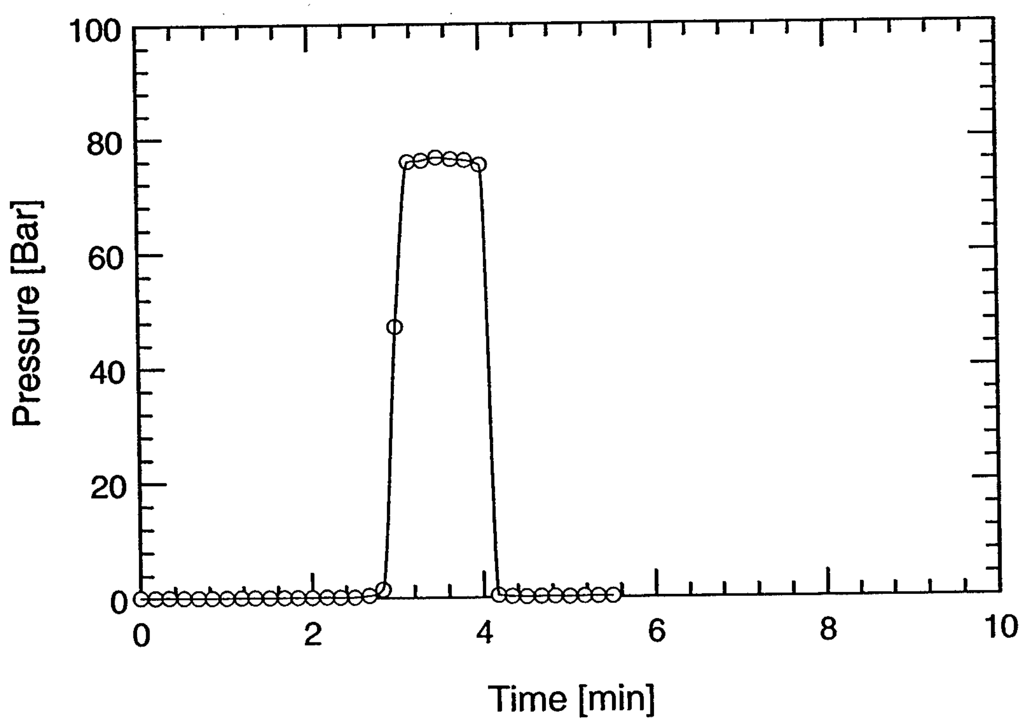


FR 22

Test #17

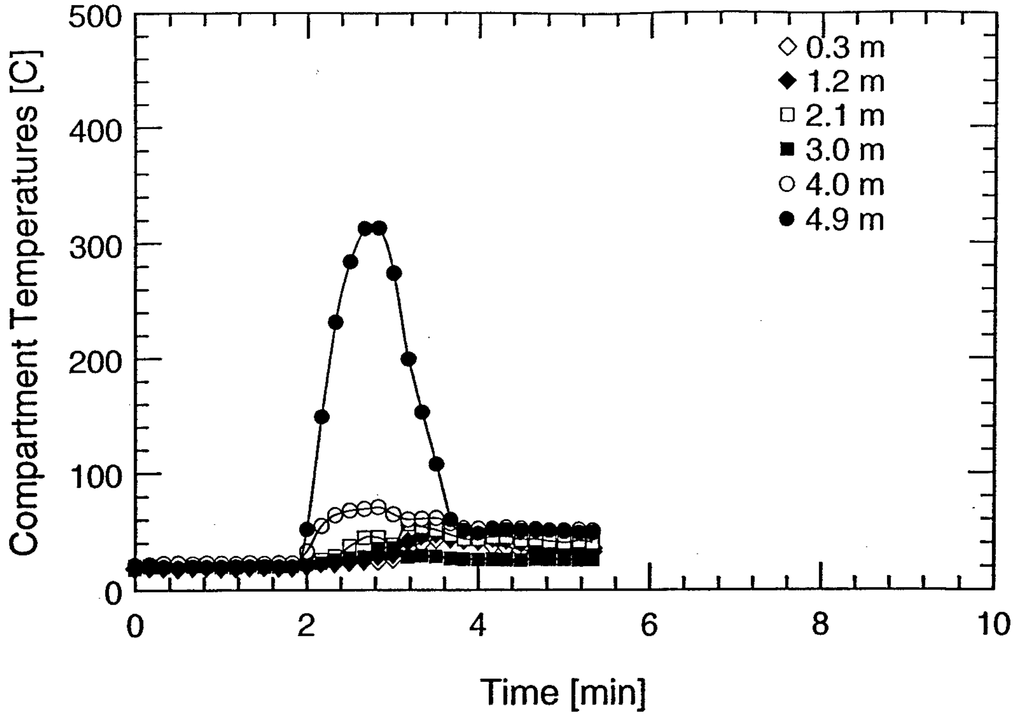


Water Mist System Flow Rate

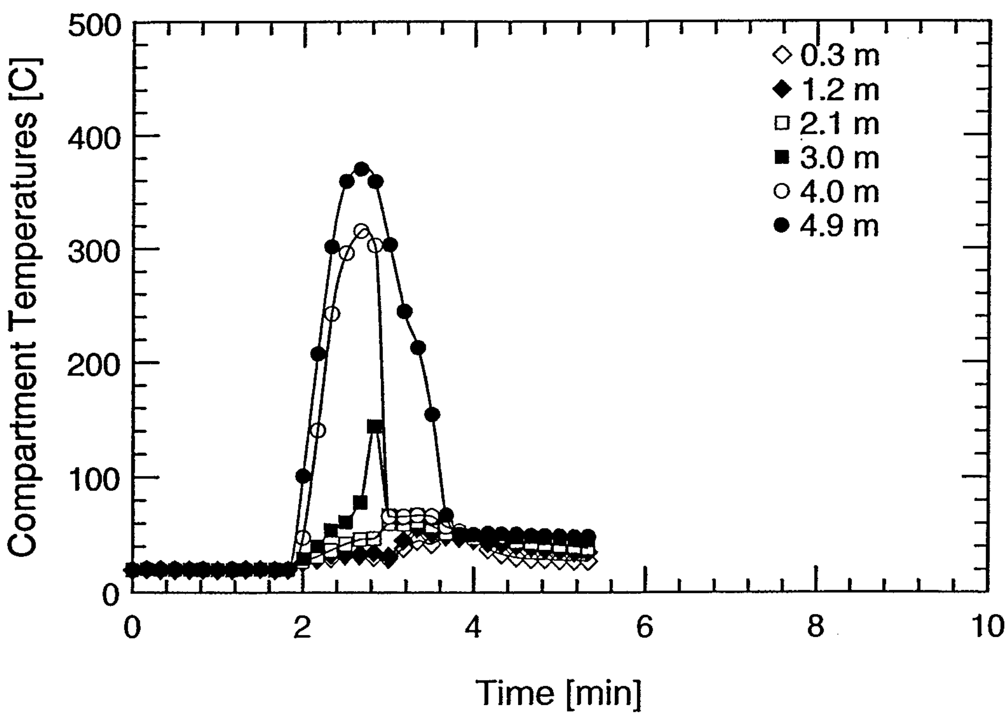


Water Mist System Pressure

Test #17

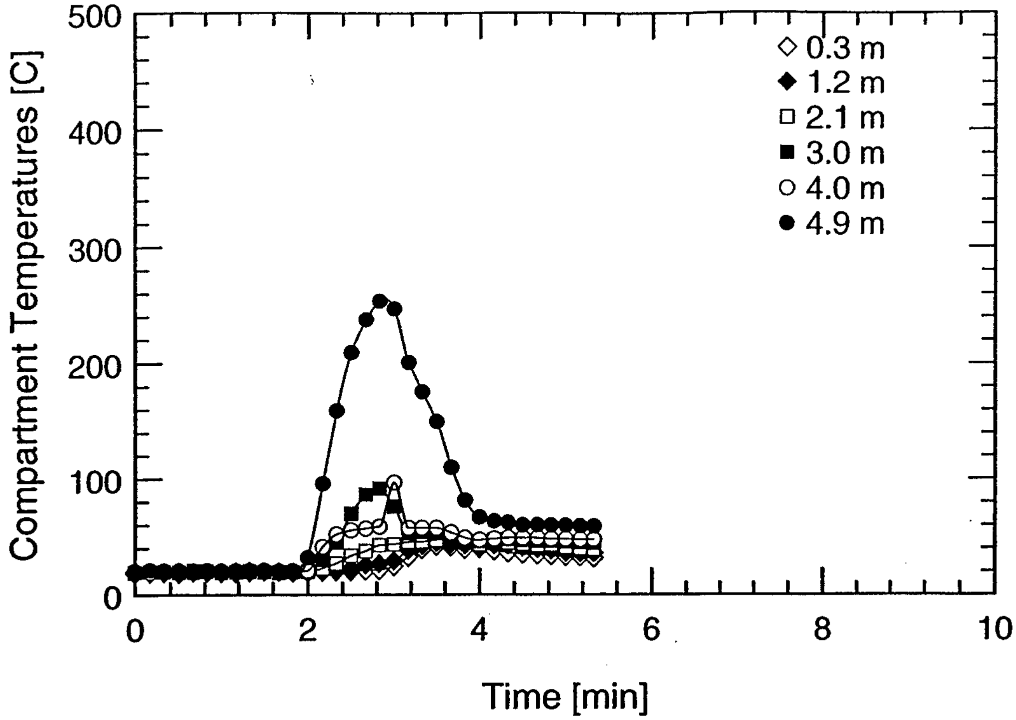


5-22-1

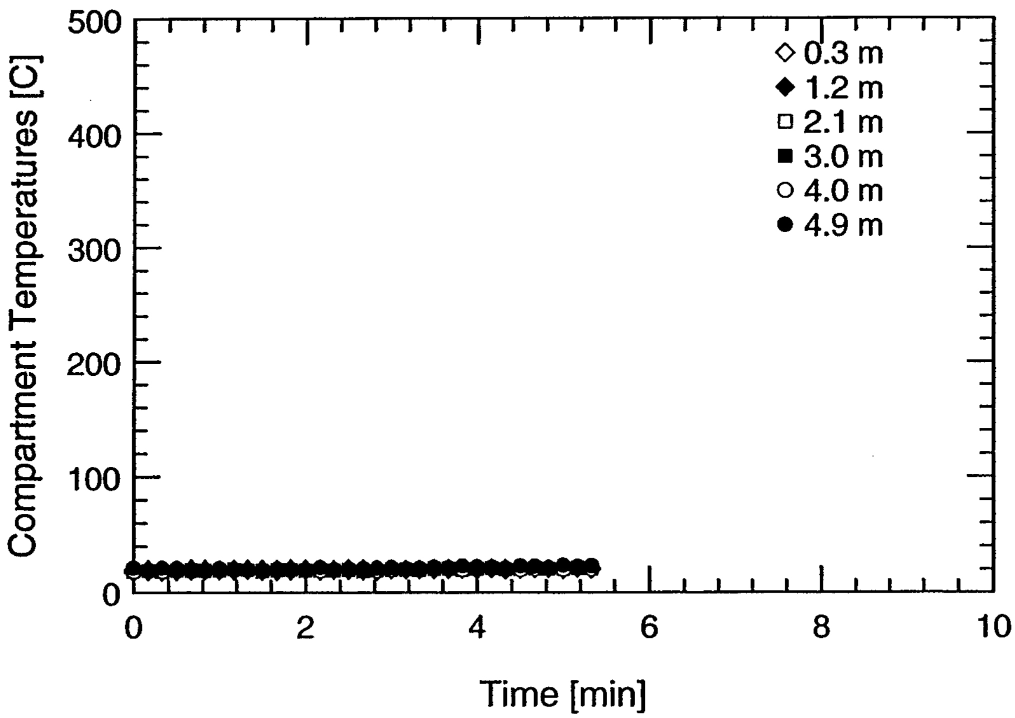


5-27-1

Test #18

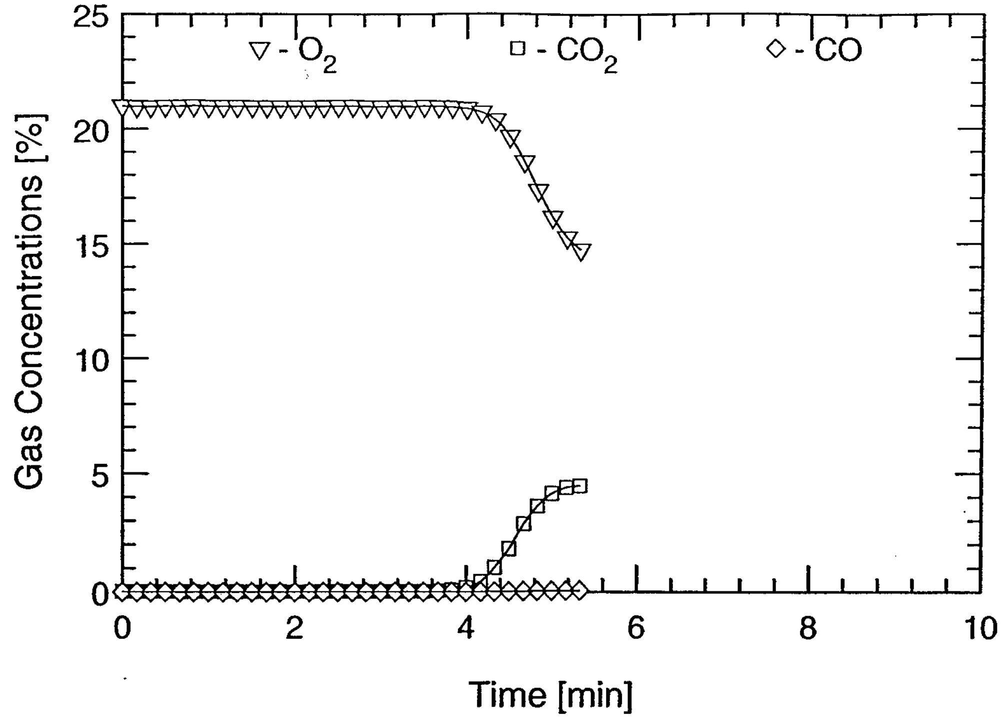


5-27-2

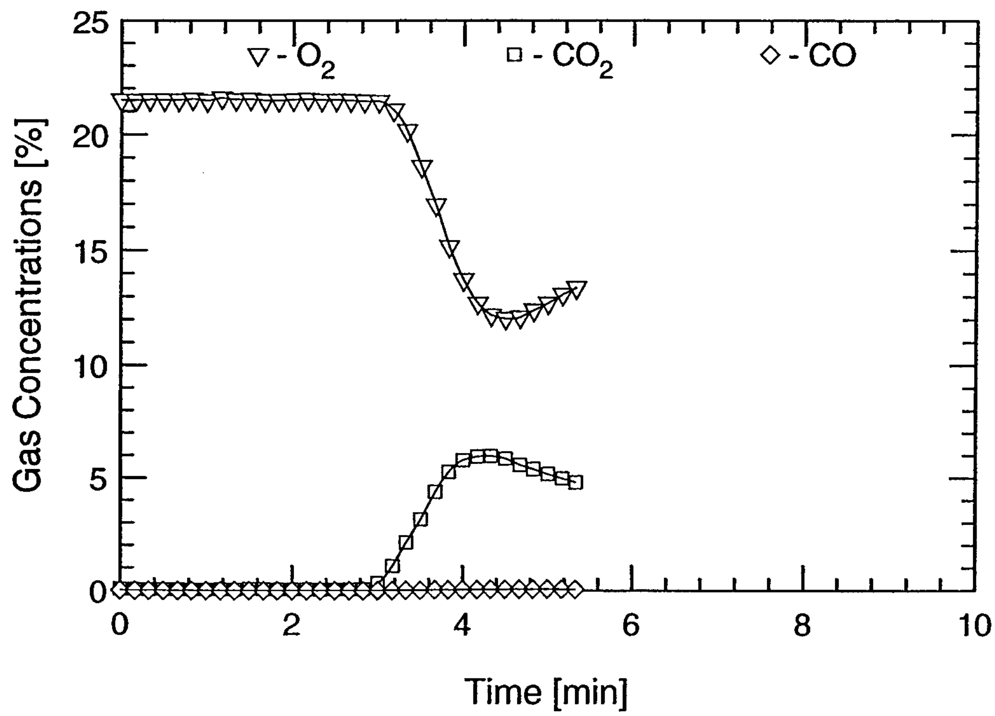


5-35-1

Test #18

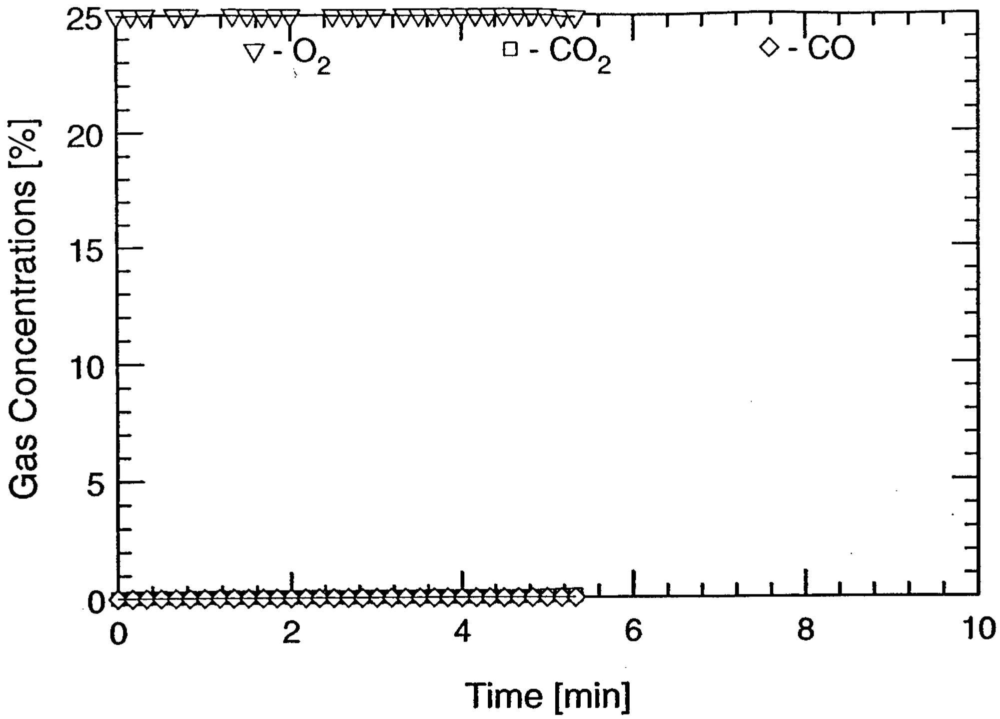


FR 22 - 0.5 m

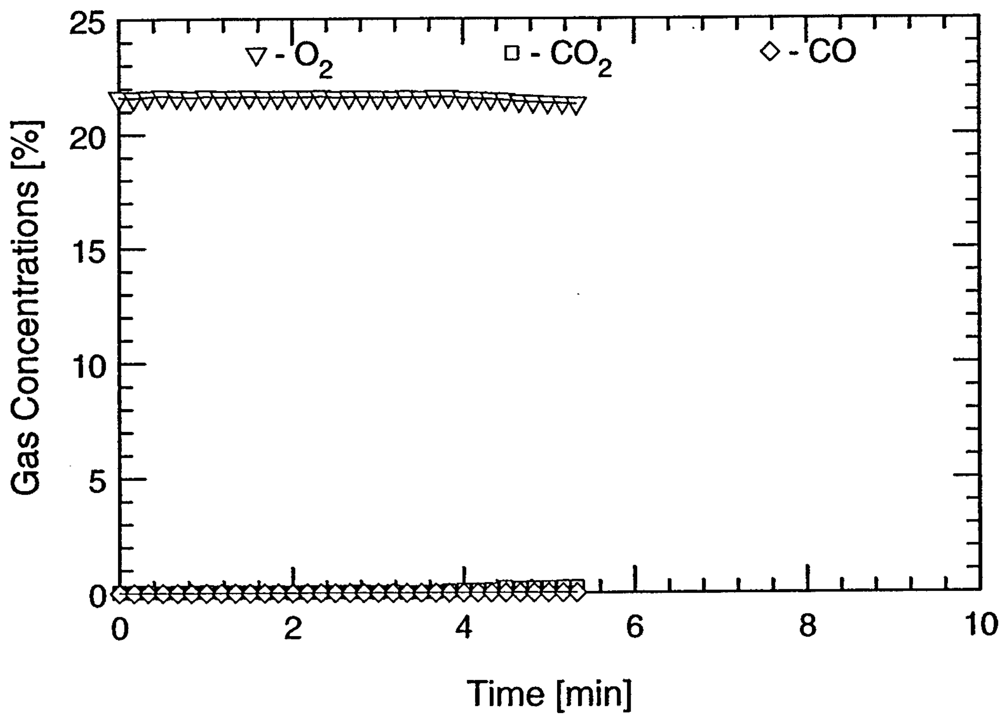


FR 22 - 4.5 m

Test #18

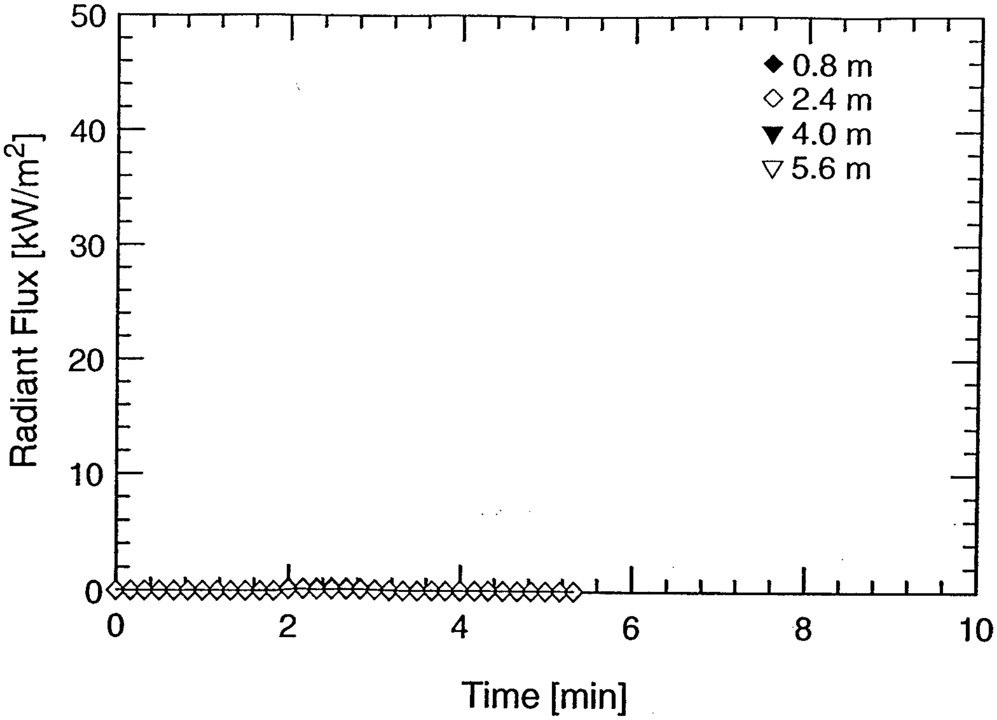


FR 36 - 0.5 m

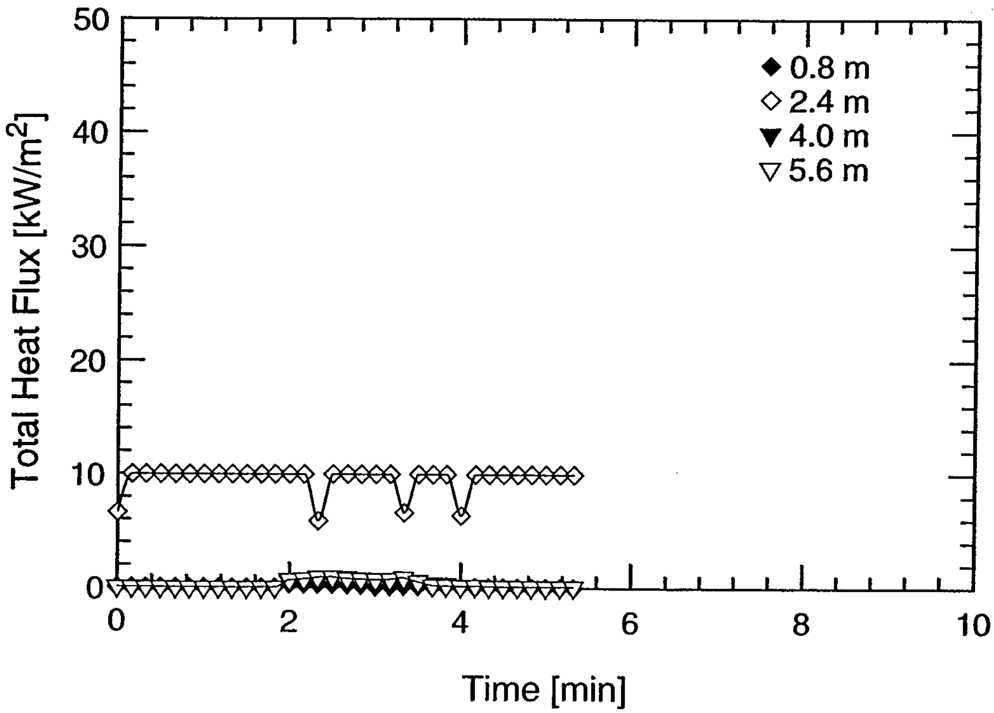


FR 36 - 4.5 m

Test #18

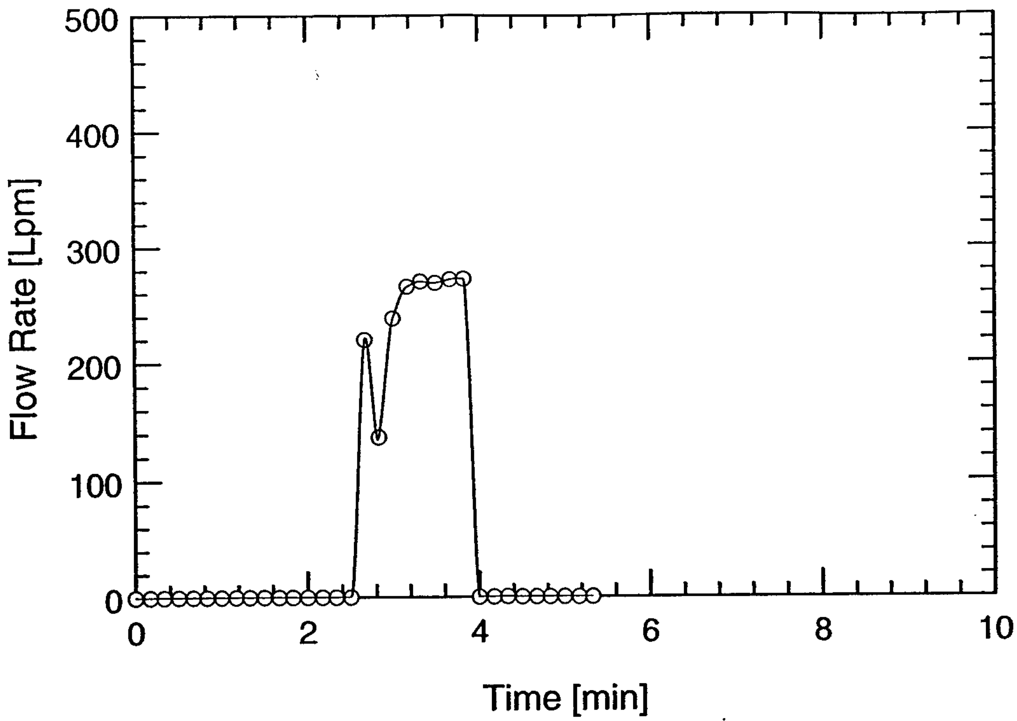


FR 22

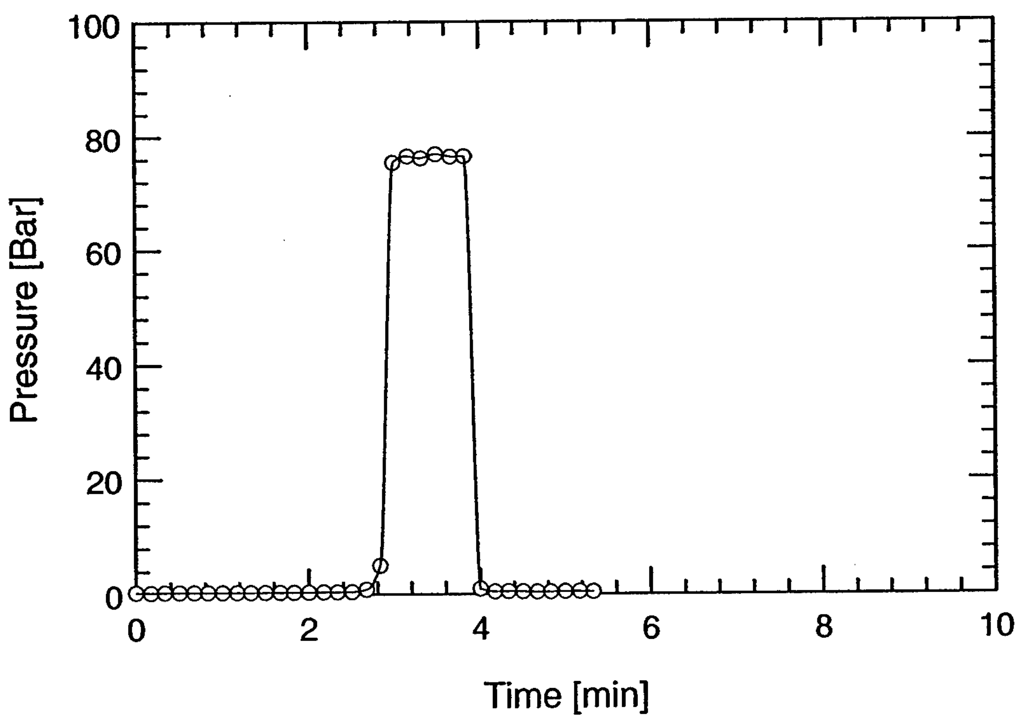


FR 22

Test #18

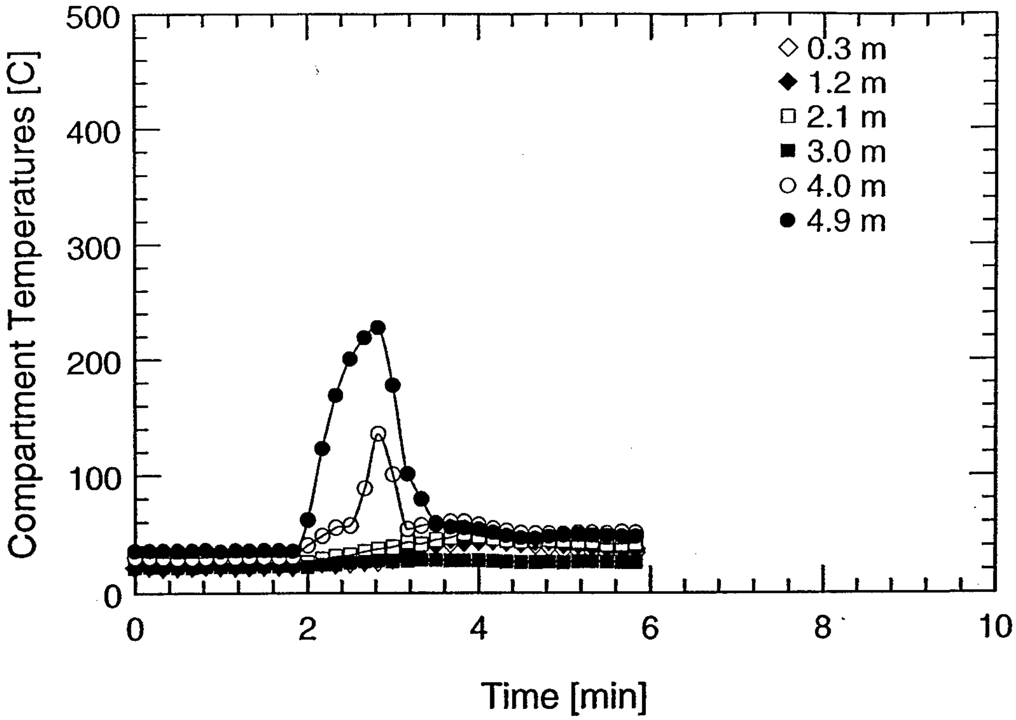


Water Mist System Flow Rate

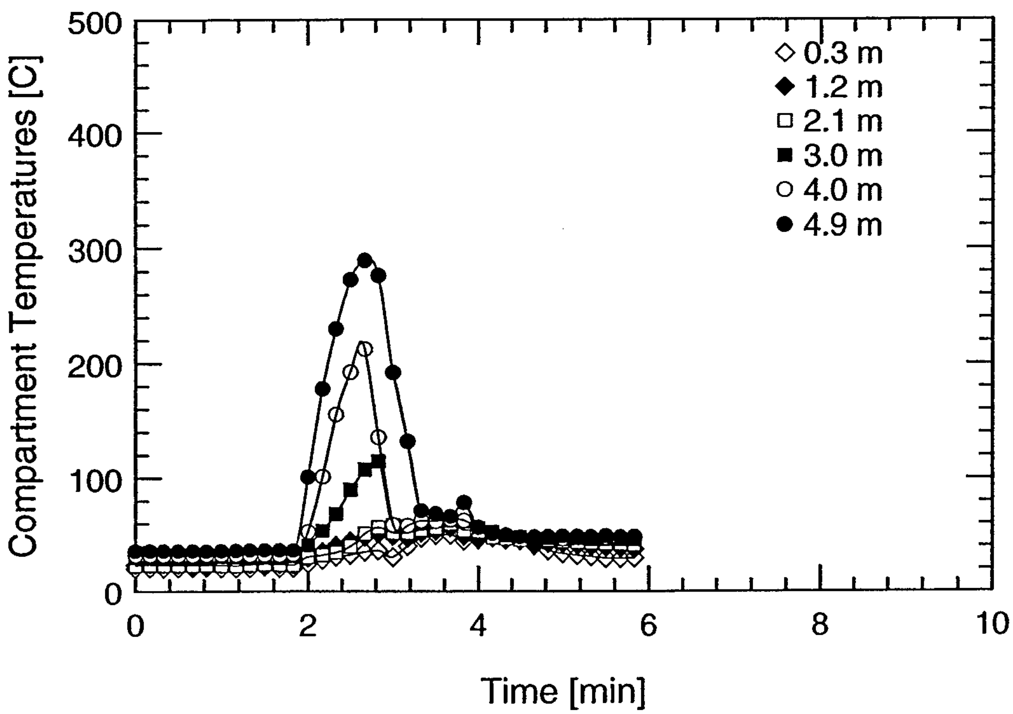


Water Mist System Pressure

Test #18

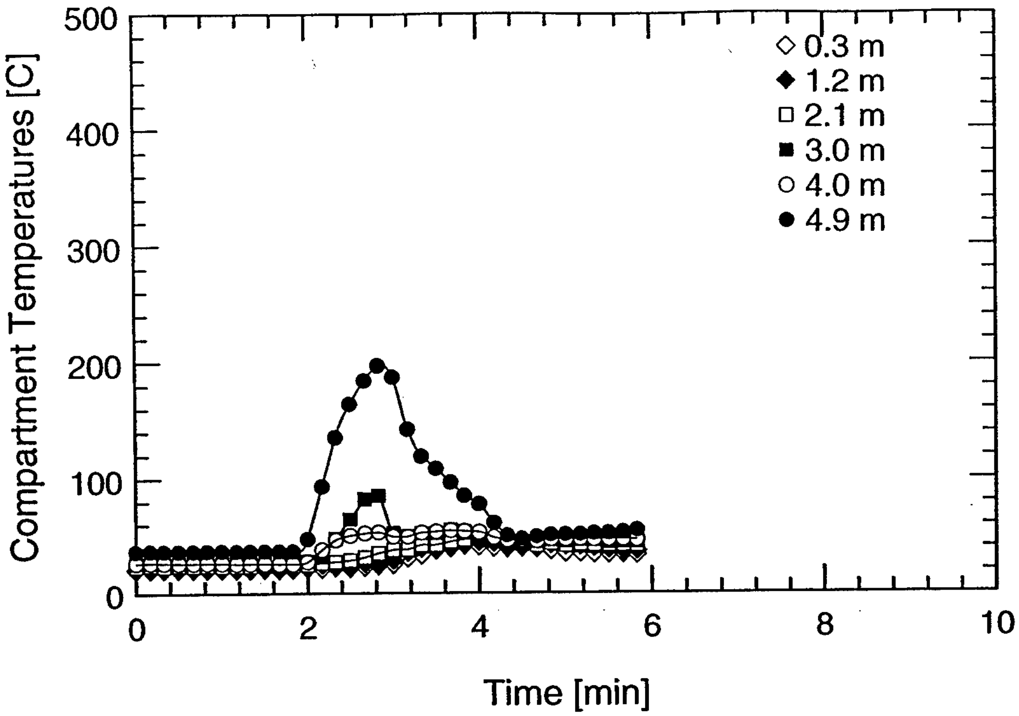


5-22-1

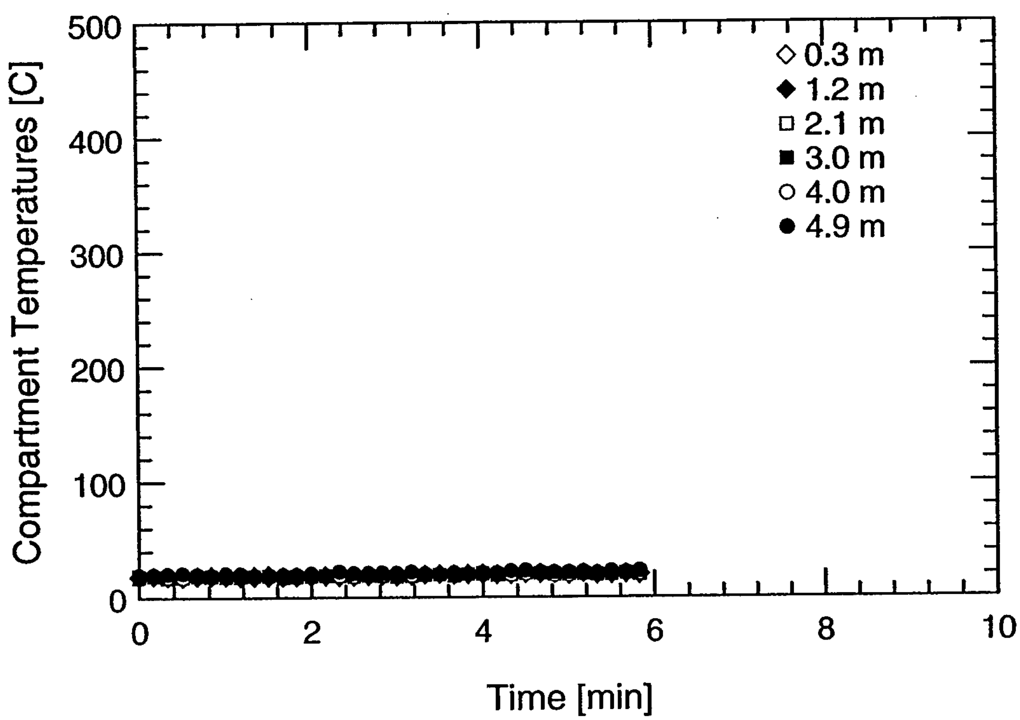


5-27-1

Test #19

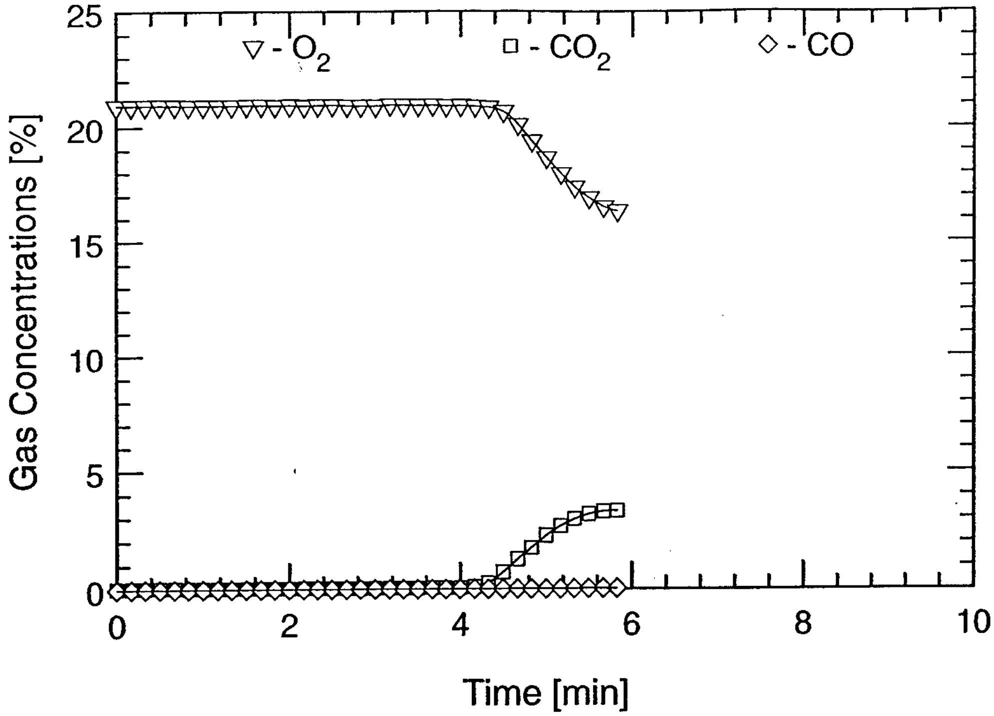


5-27-2

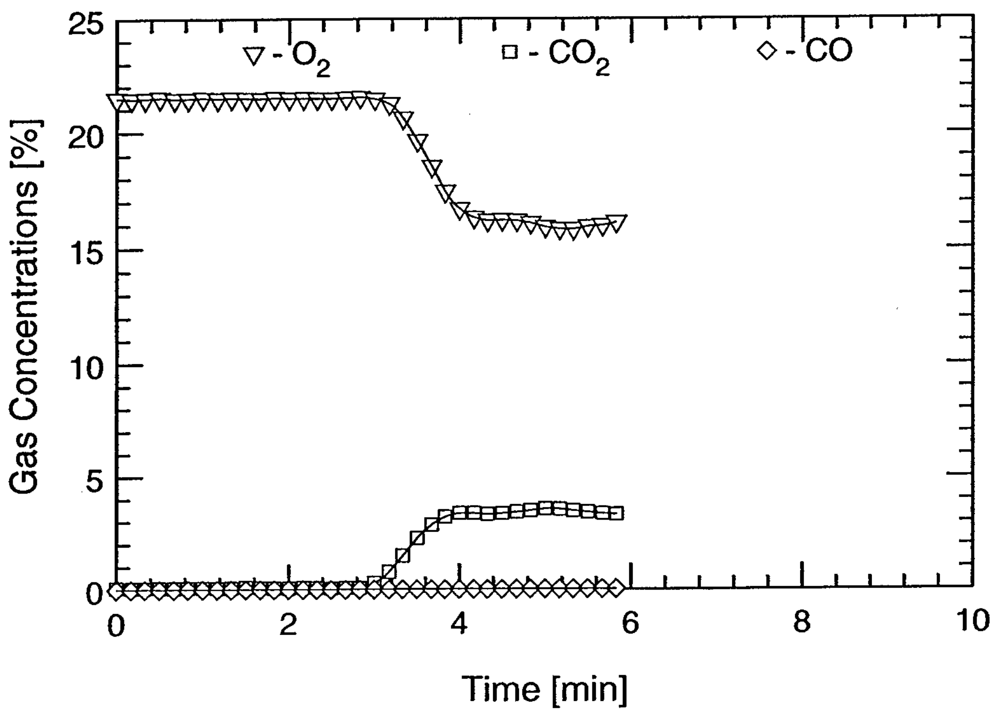


5-35-1

Test #19

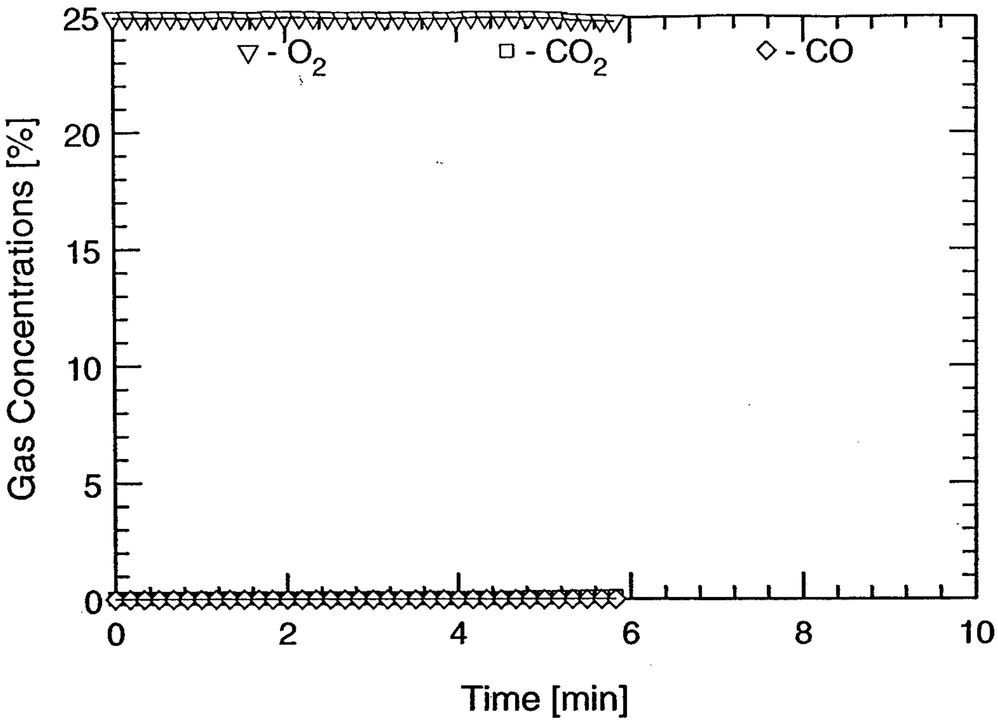


FR 22 - 0.5 m

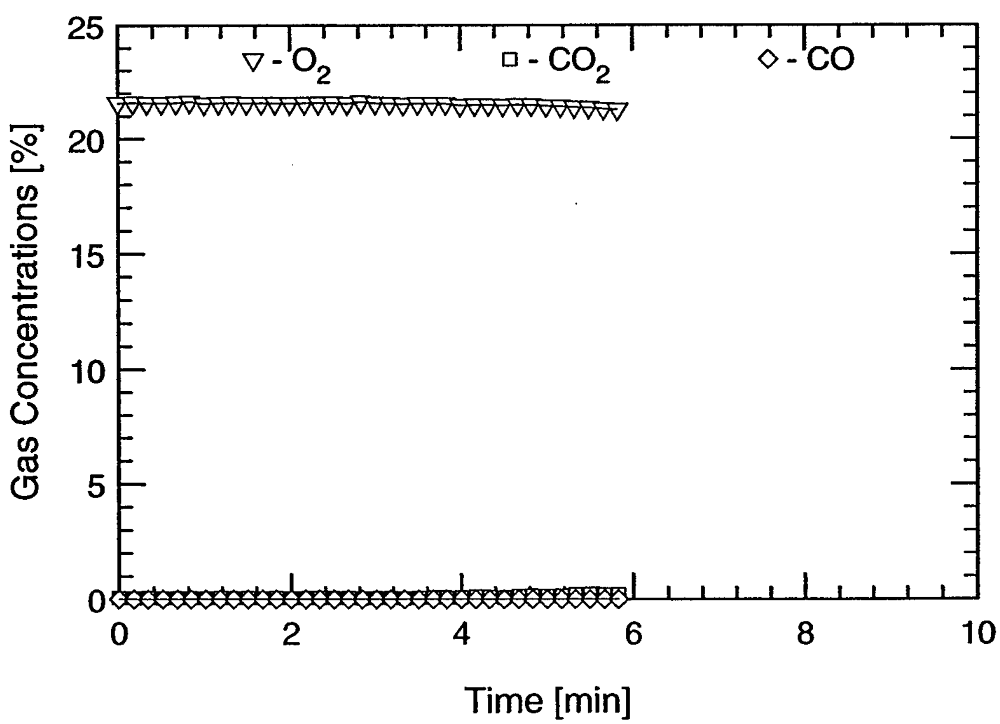


FR 22 - 4.5 m

Test #19

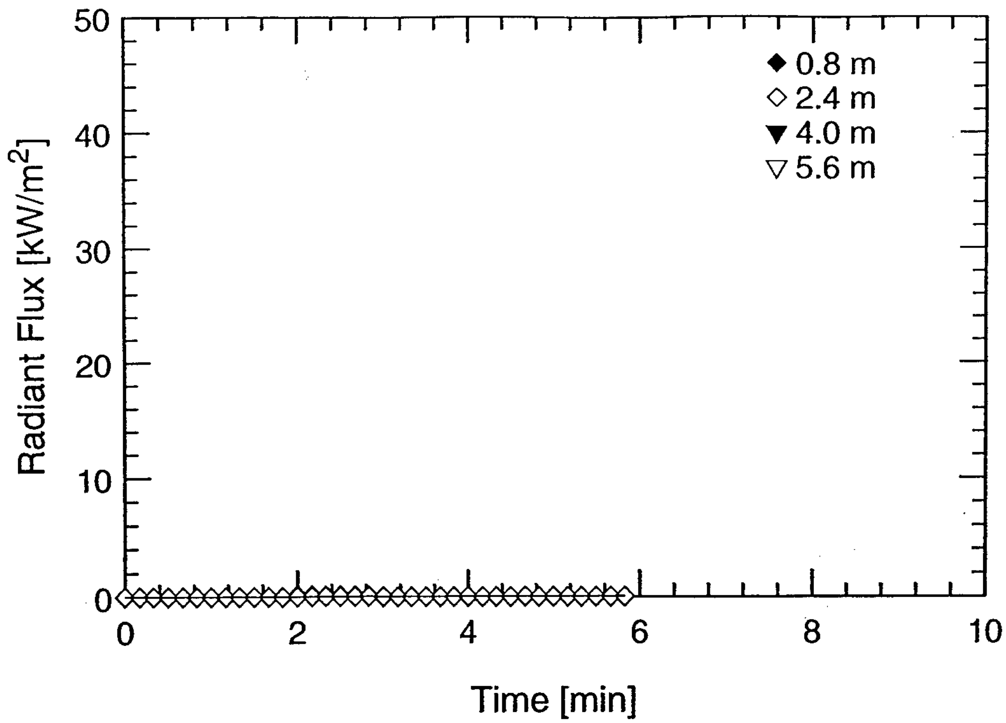


FR 36 - 0.5 m

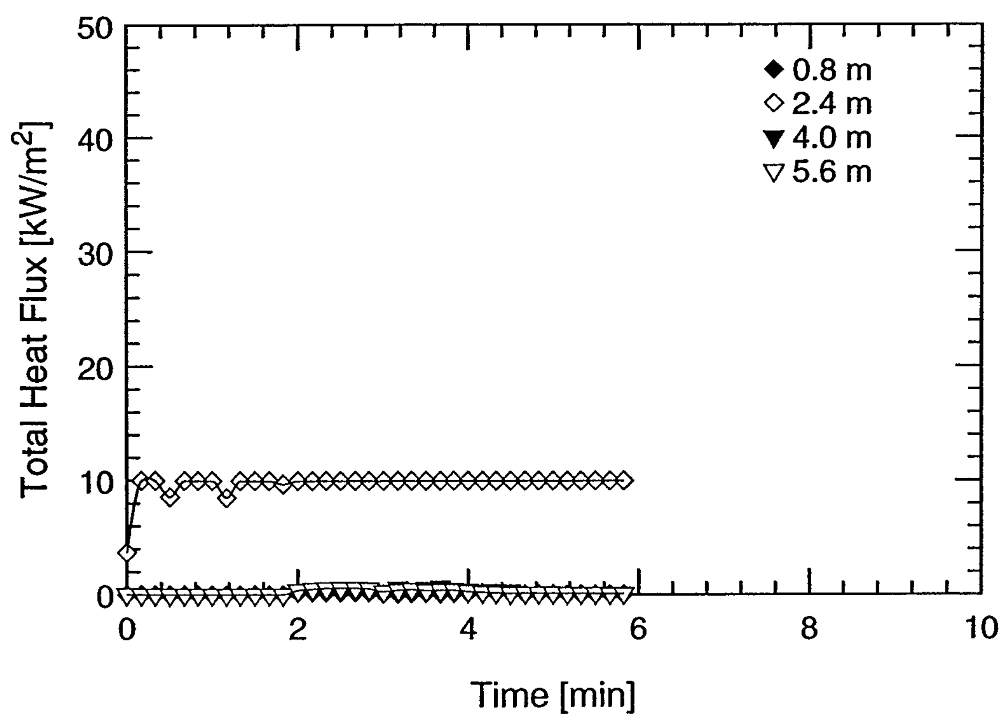


FR 36 - 4.5 m

Test #19

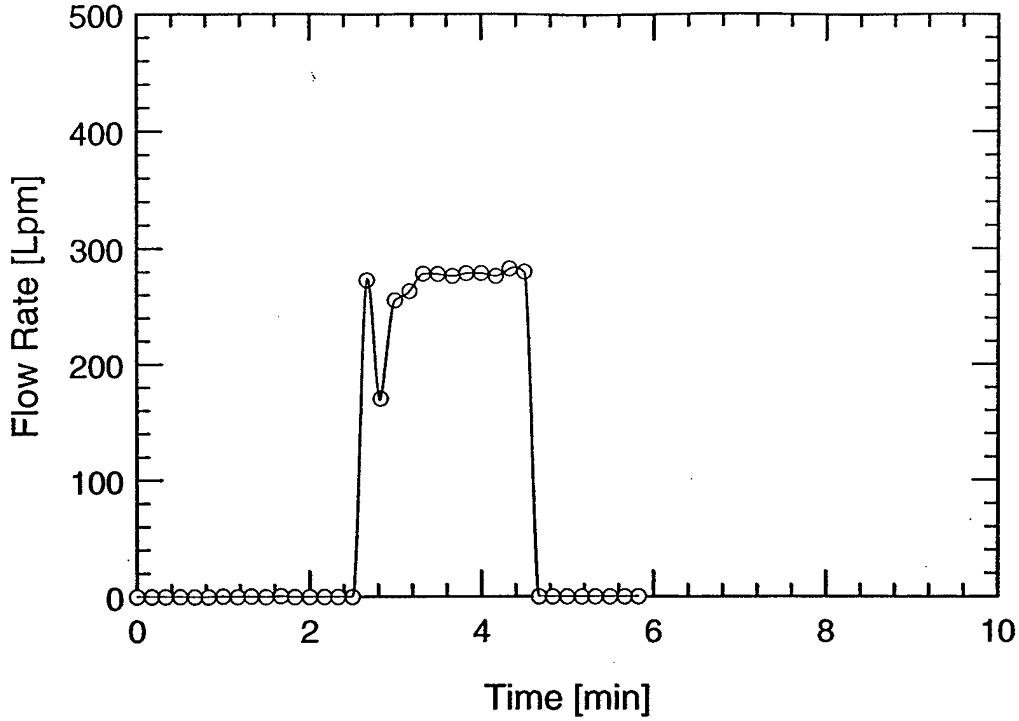


FR 22

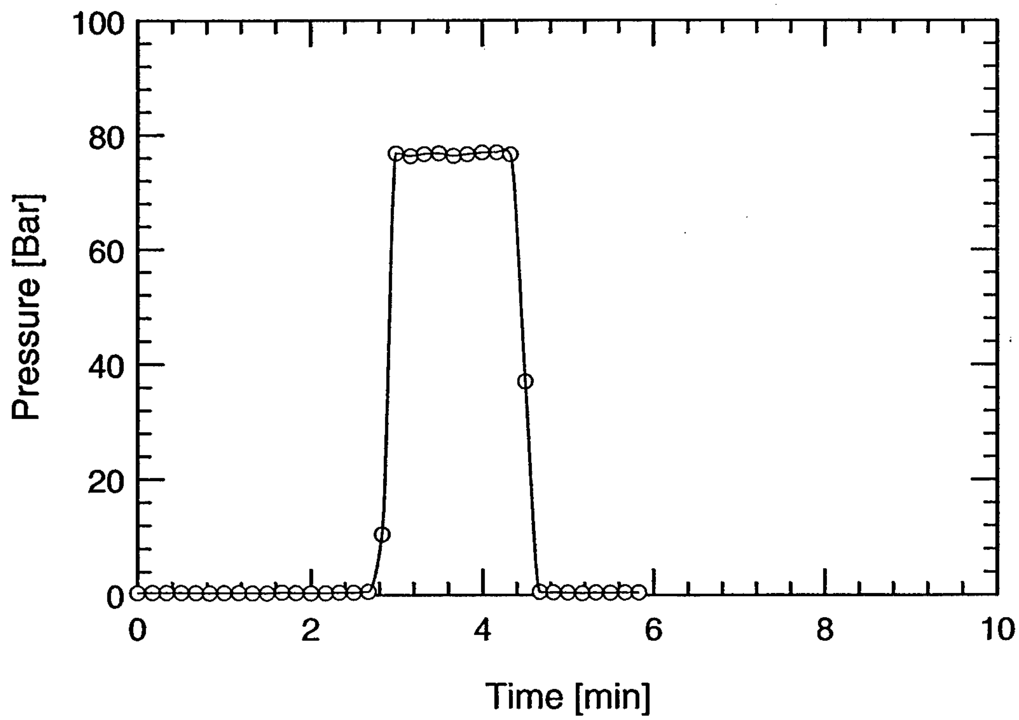


FR 22

Test #19

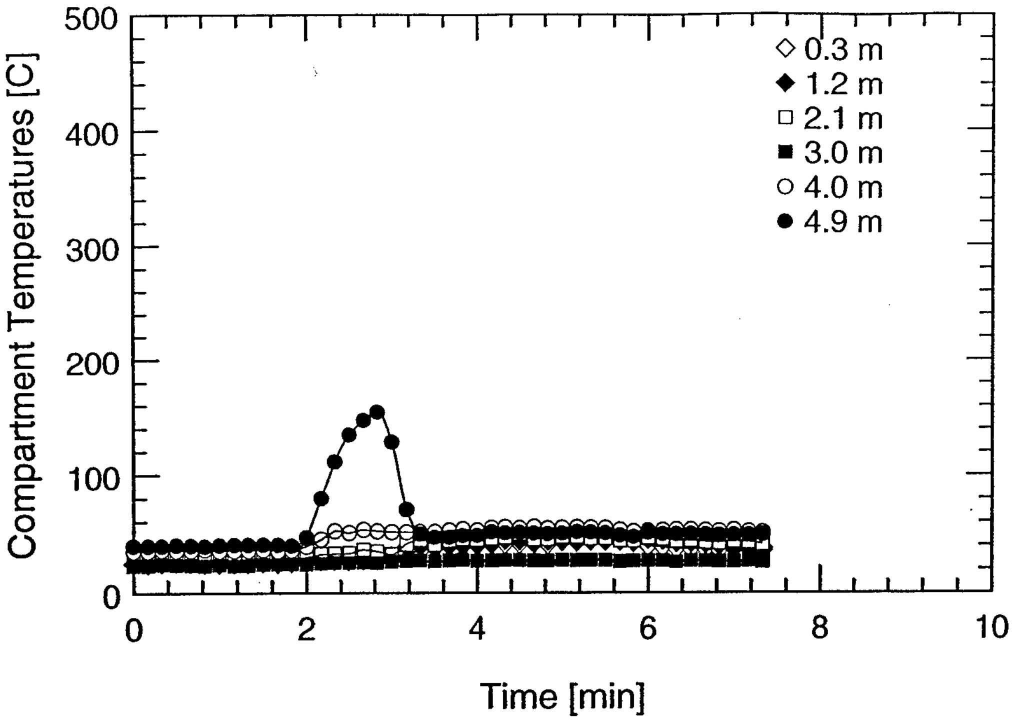


Water Mist System Flow Rate

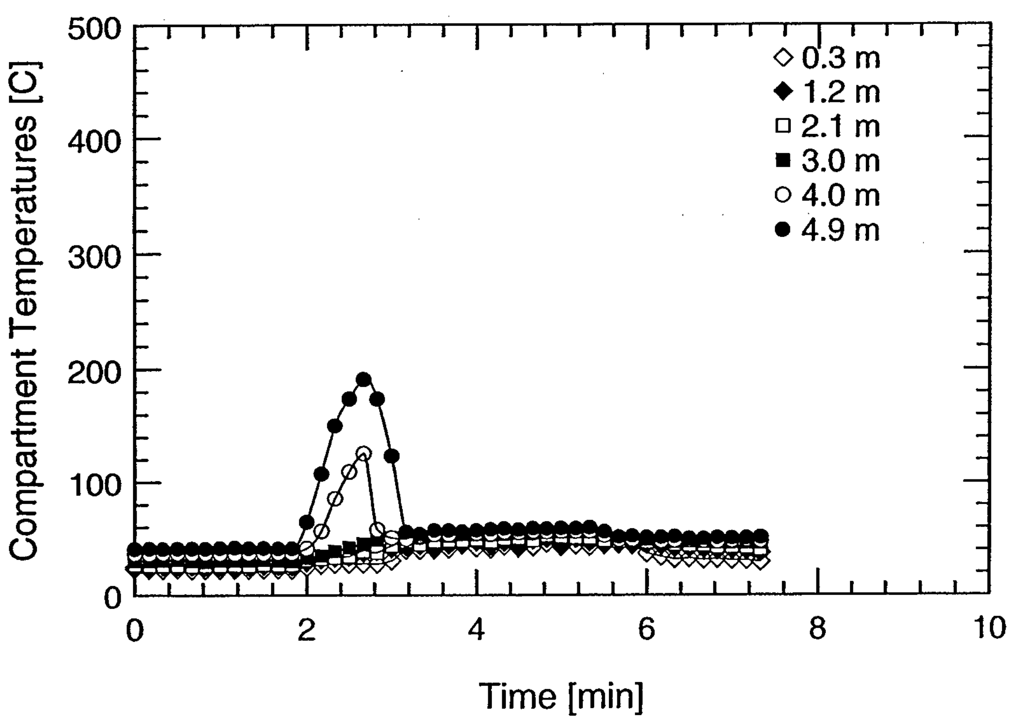


Water Mist System Pressure

Test #19

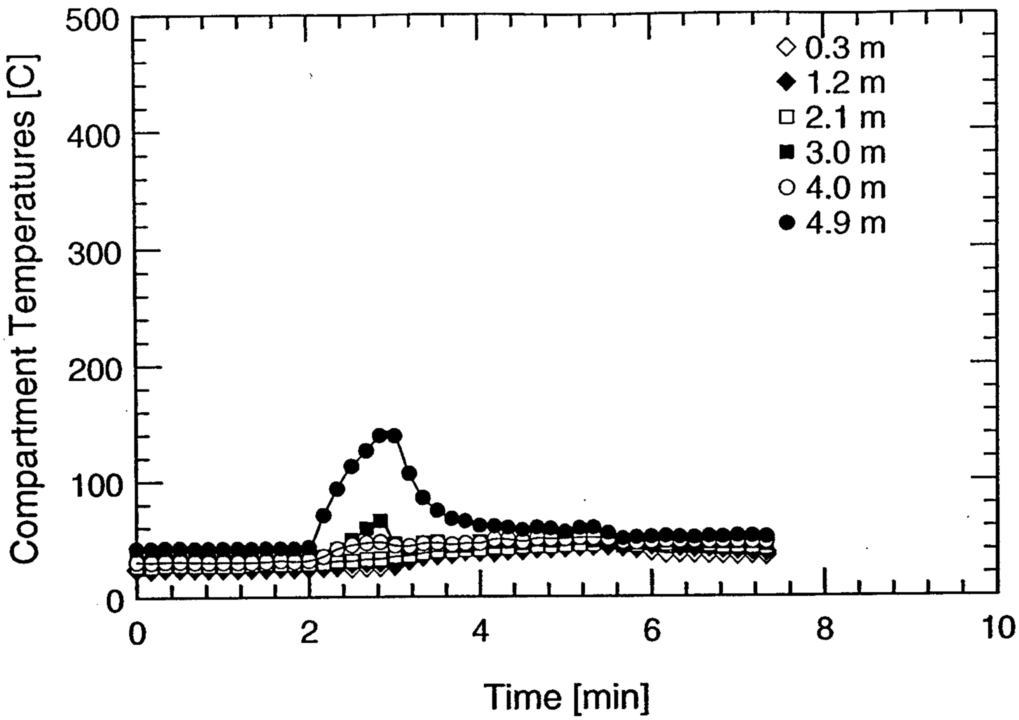


5-22-1

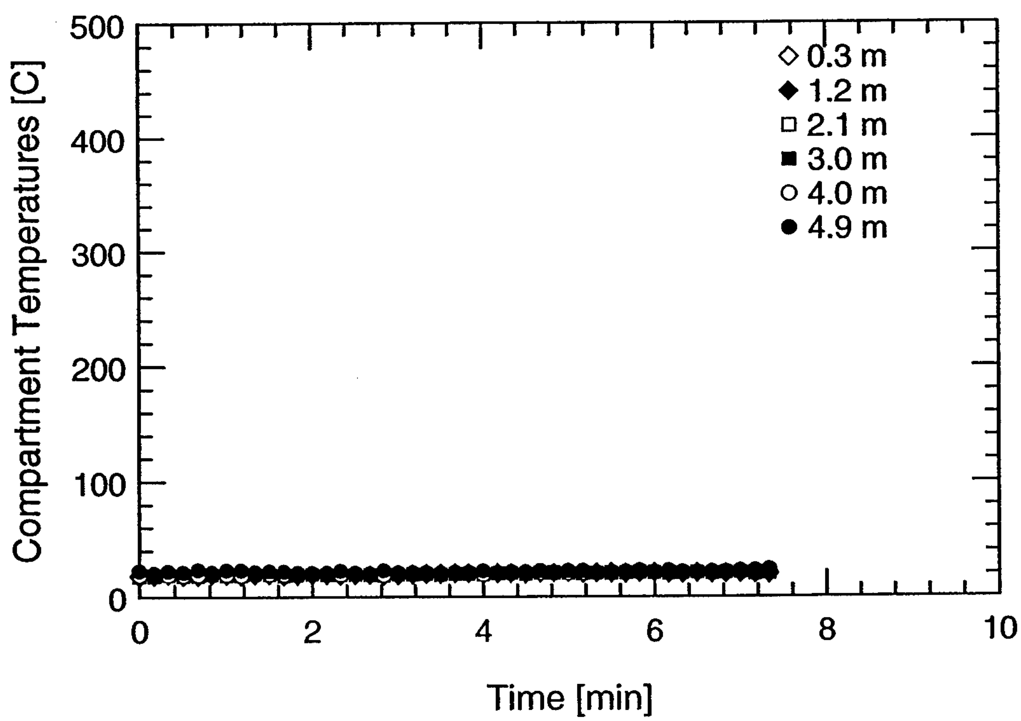


5-27-1

Test #20

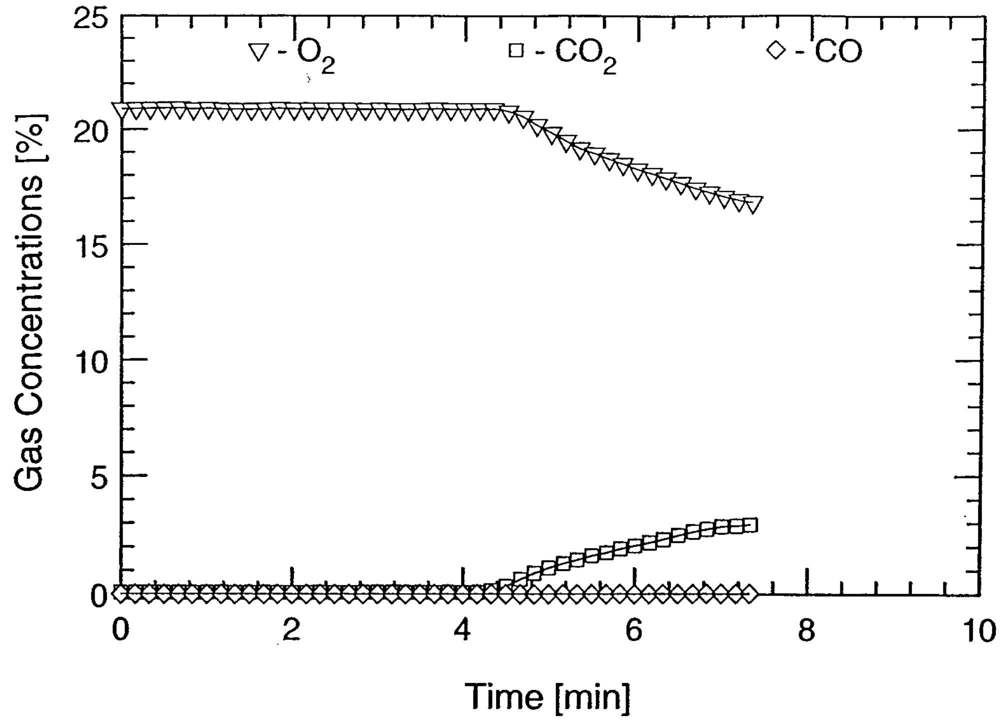


5-27-2

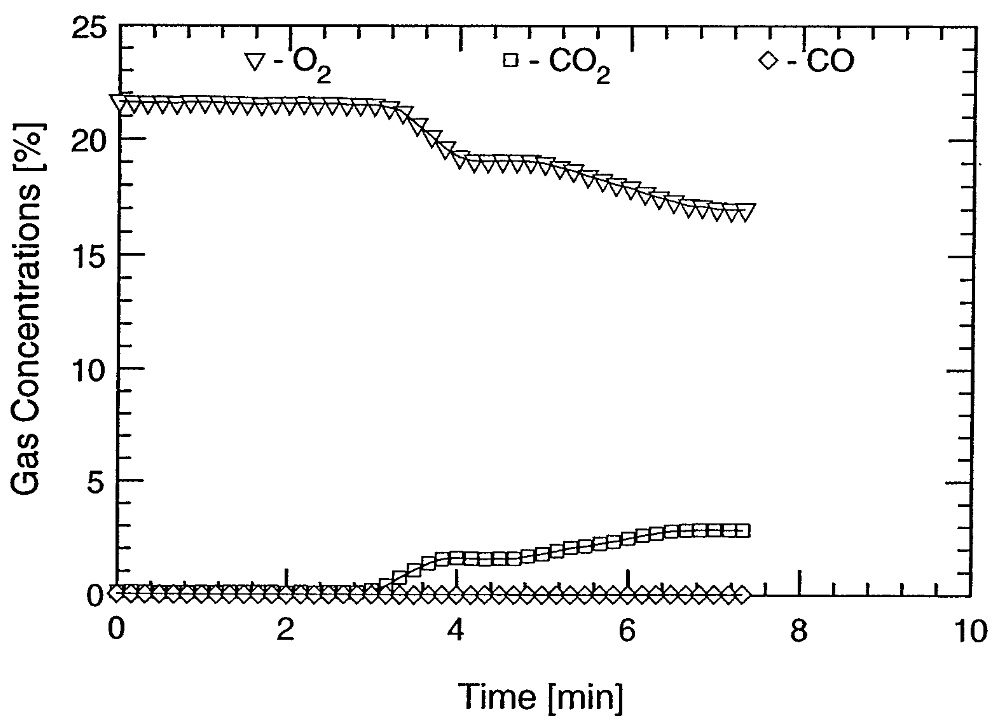


5-35-1

Test #20

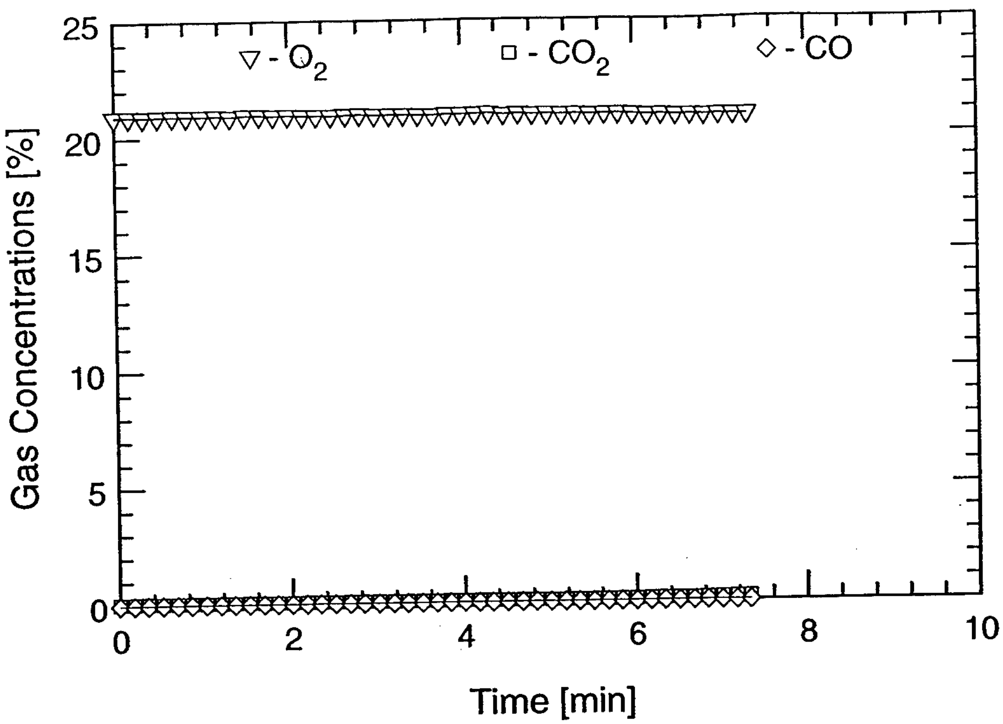


FR 22 - 0.5 m

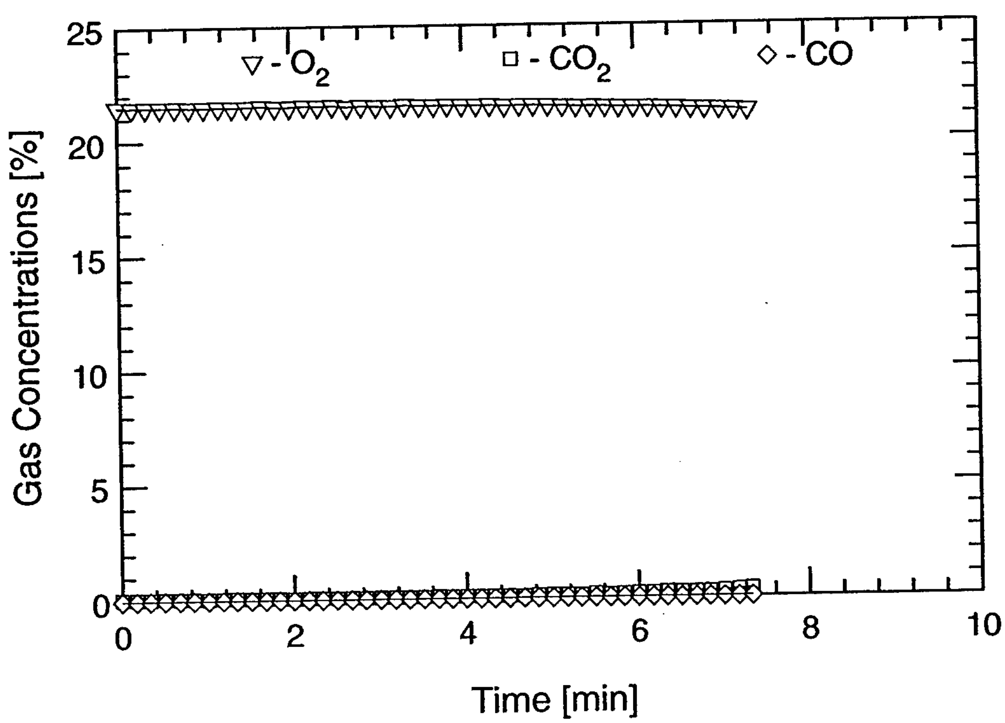


FR 22 - 4.5 m

Test #20

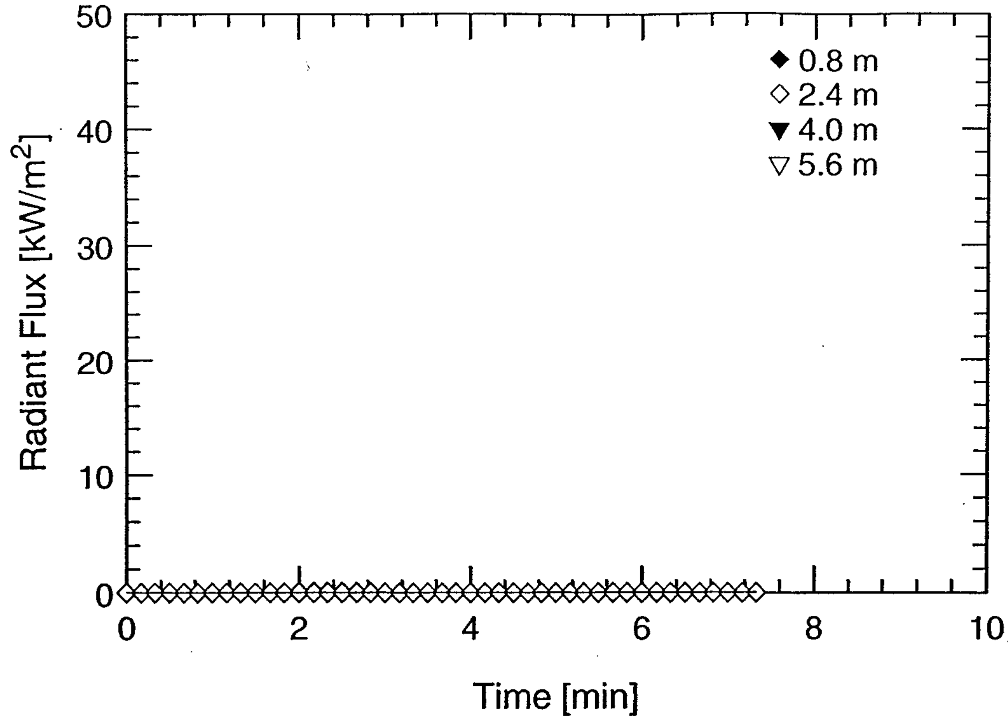


FR 36 - 0.5 m

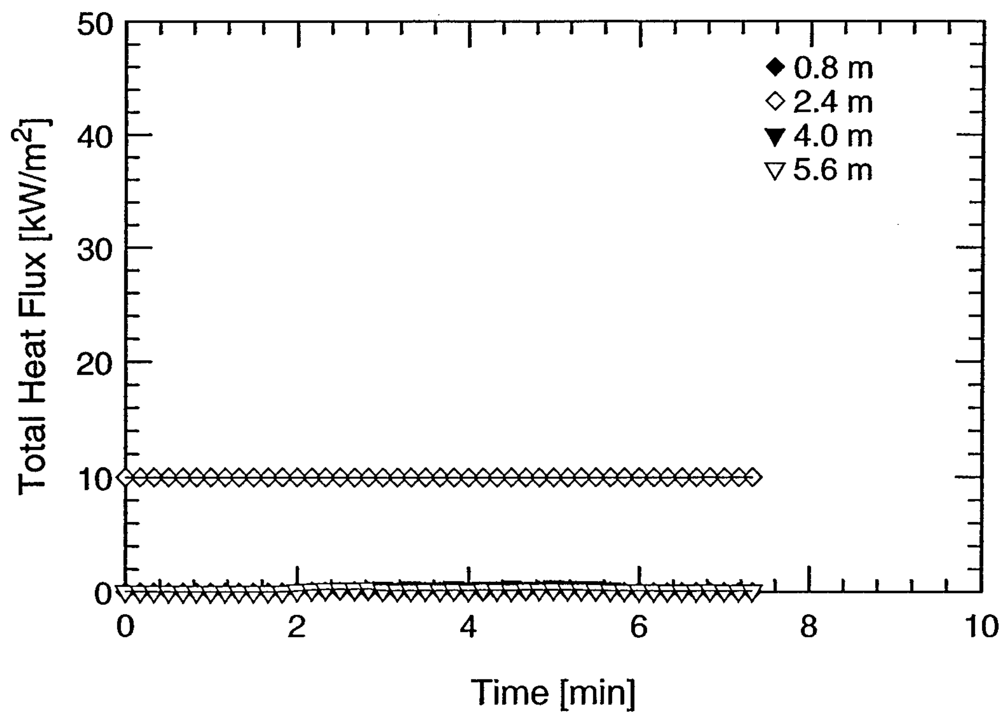


FR 36 - 4.5 m

Test #20

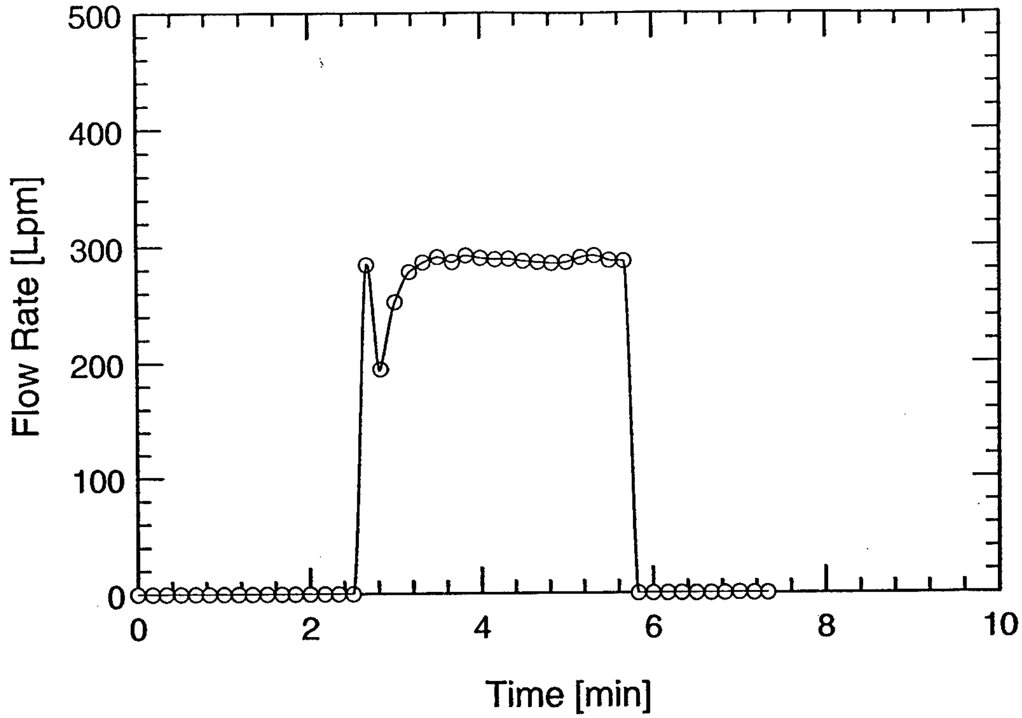


FR 22

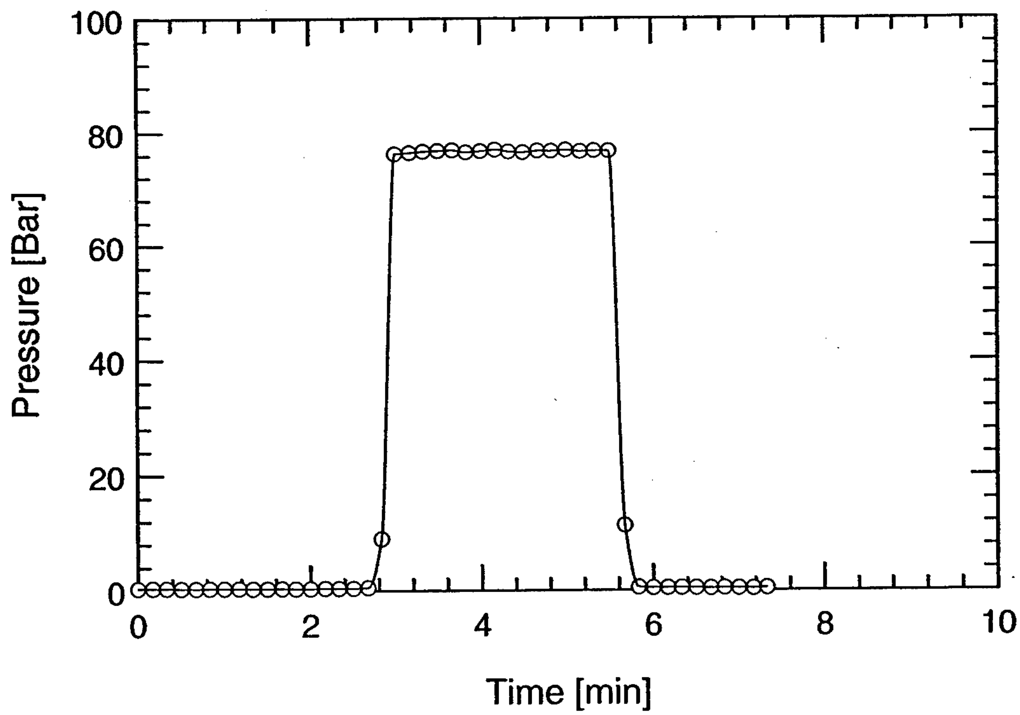


FR 22

Test #20

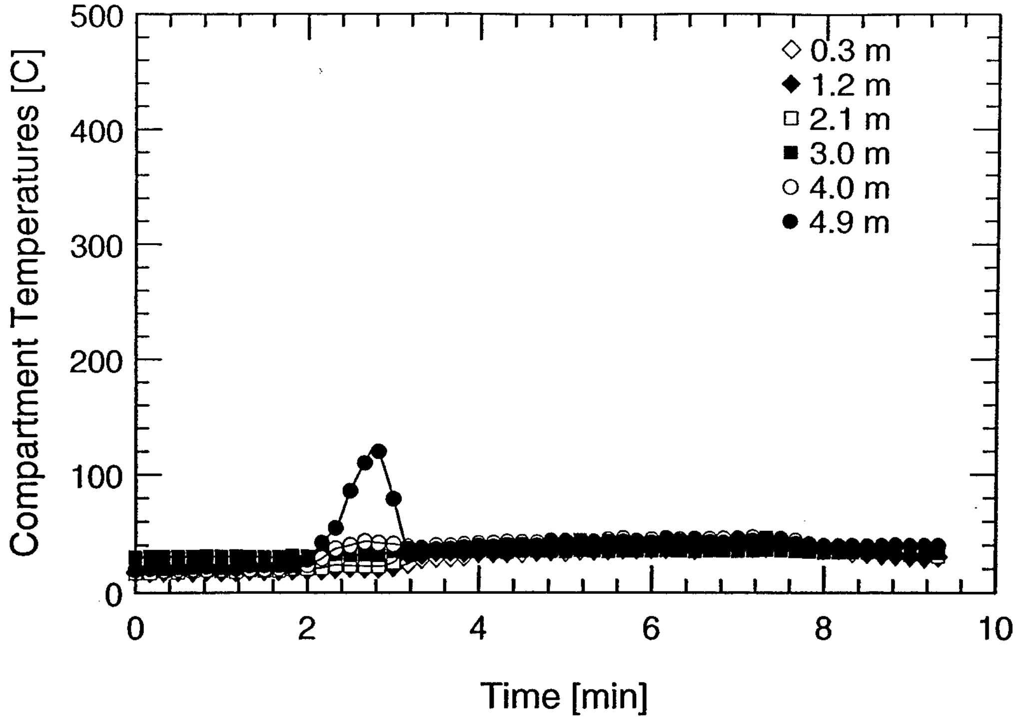


Water Mist System Flow Rate

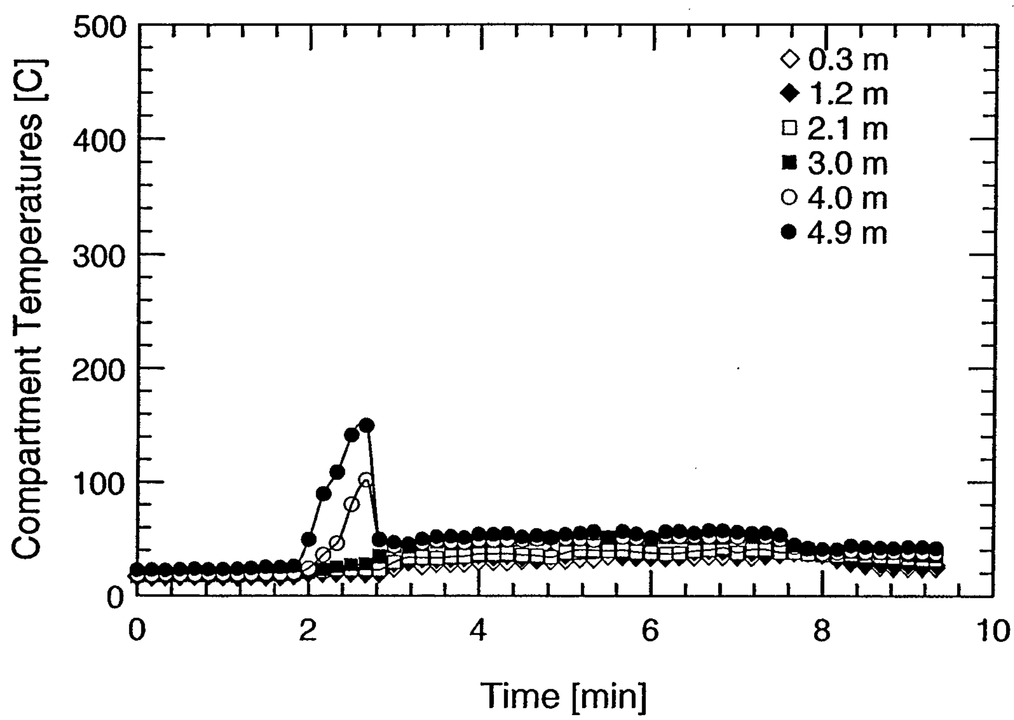


Water Mist System Pressure

Test #20

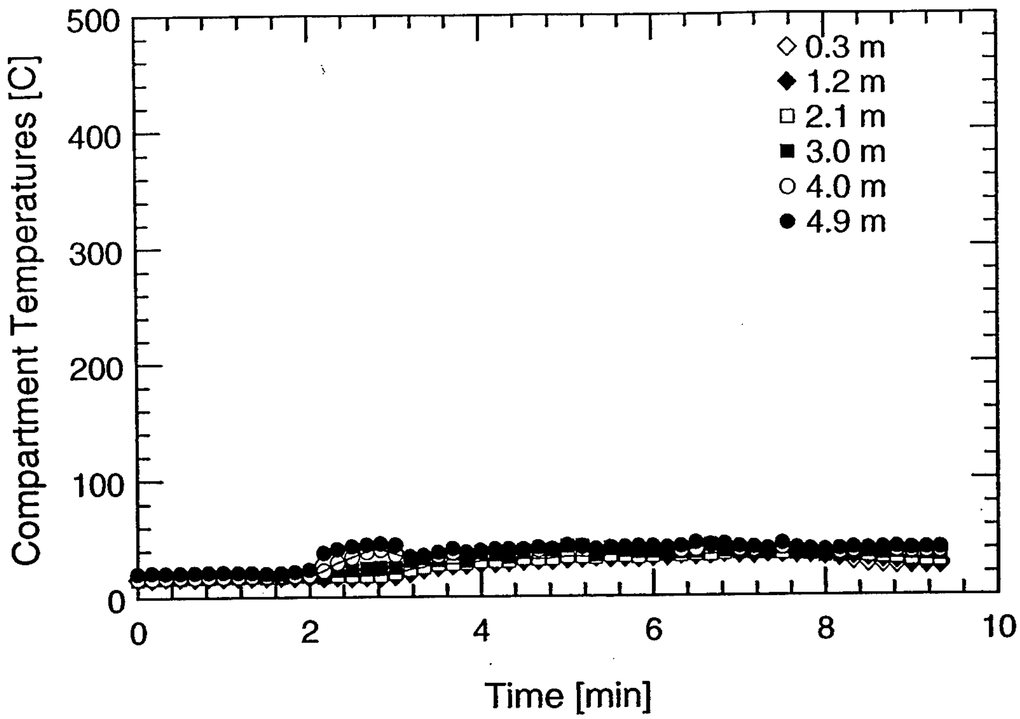


5-22-1

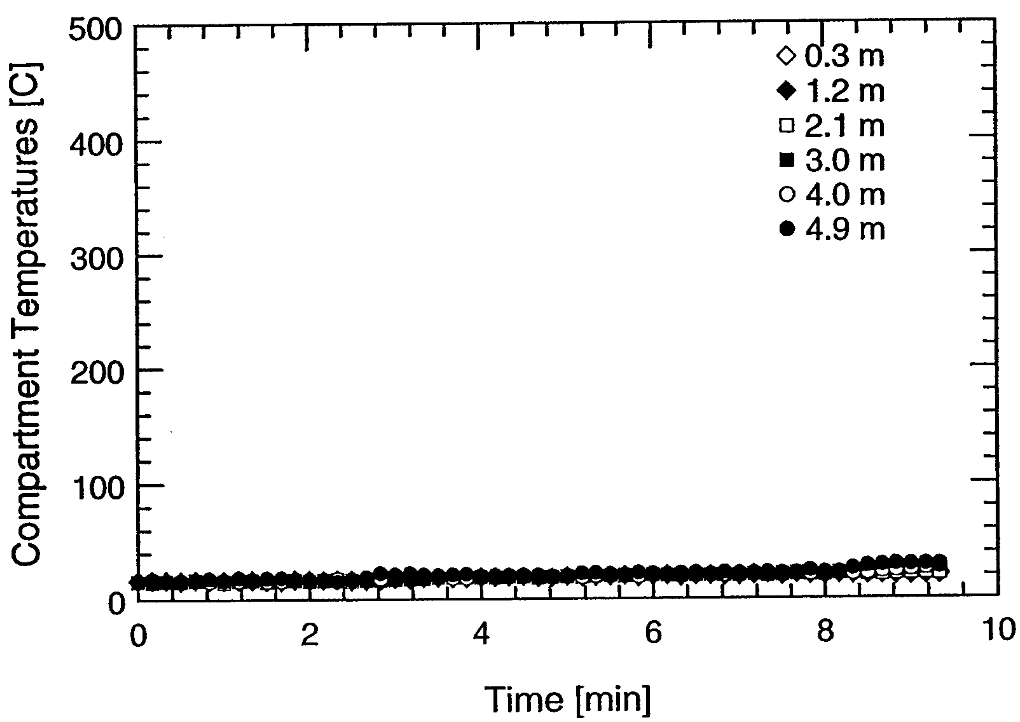


5-27-1

Test #21

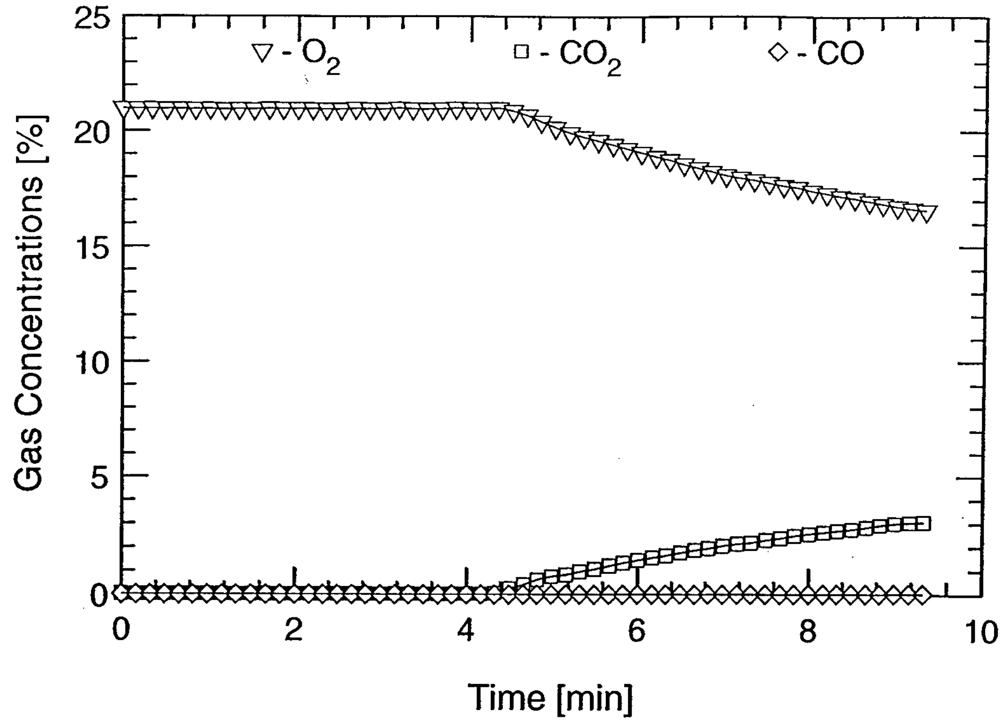


5-27-2

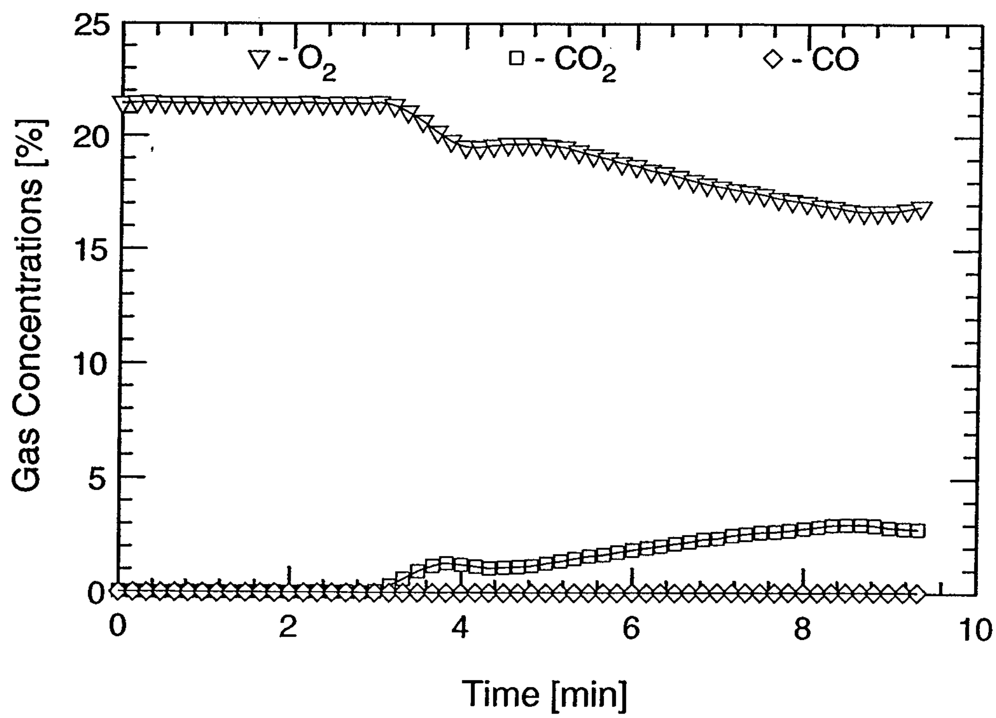


5-35-1

Test #21

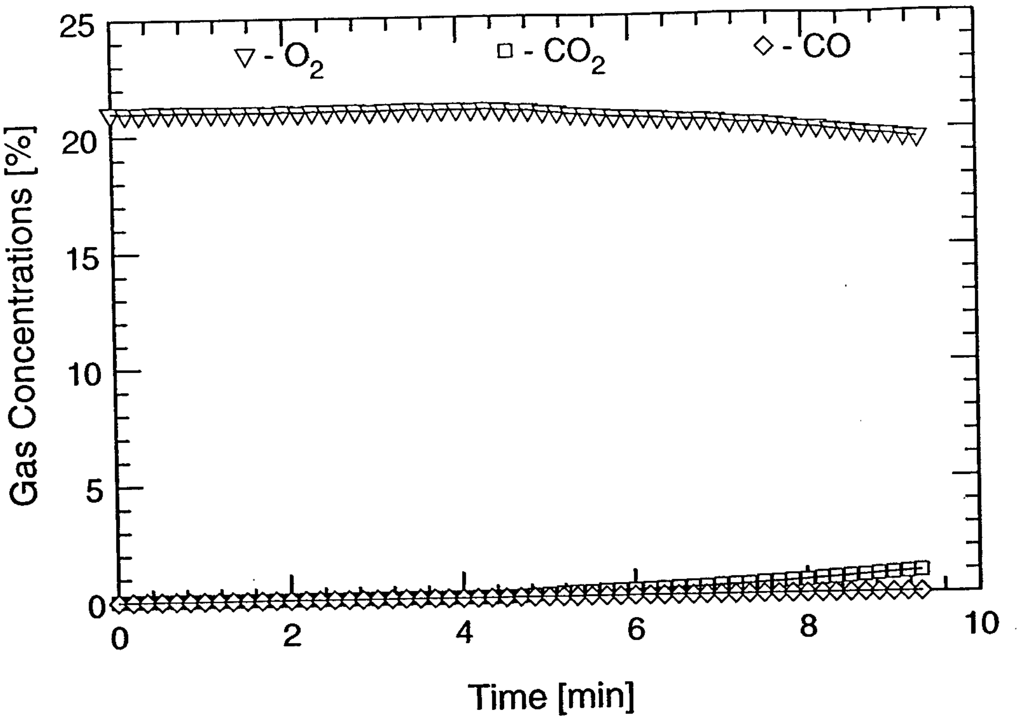


FR 22 - 0.5 m

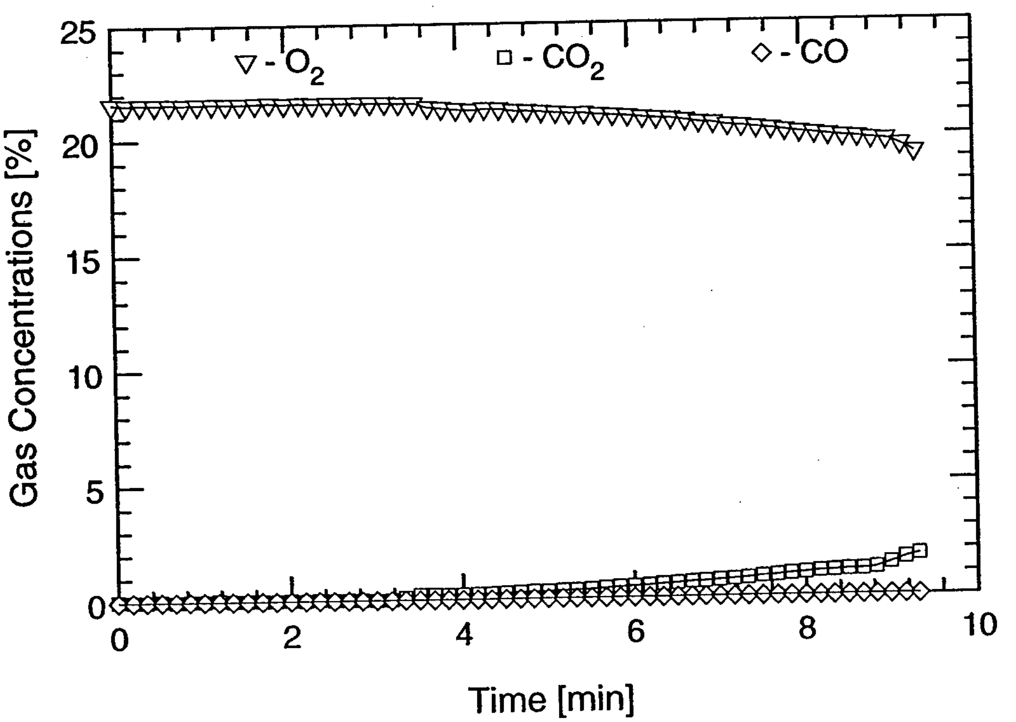


FR 22 - 4.5 m

Test #21

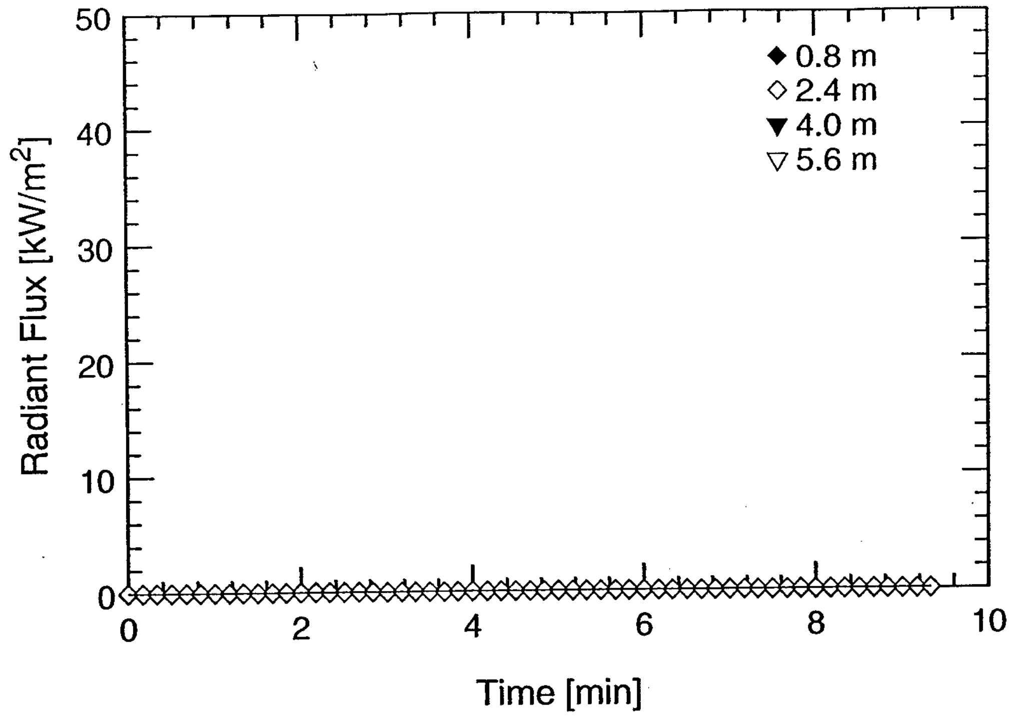


FR 36 - 0.5 m

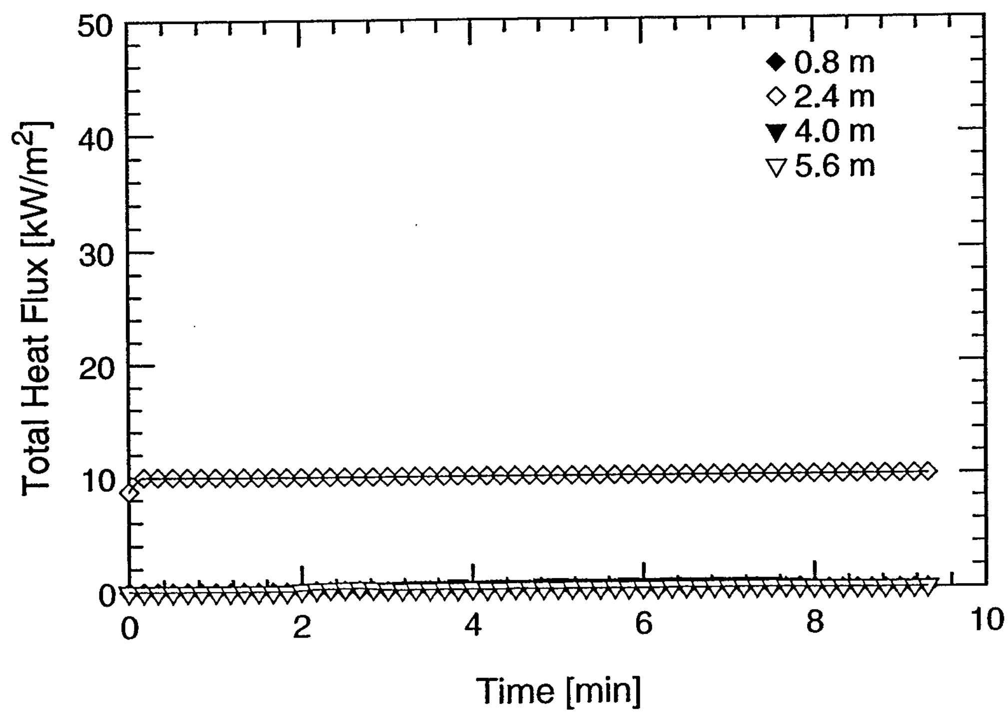


FR 36 - 4.5 m

Test #21

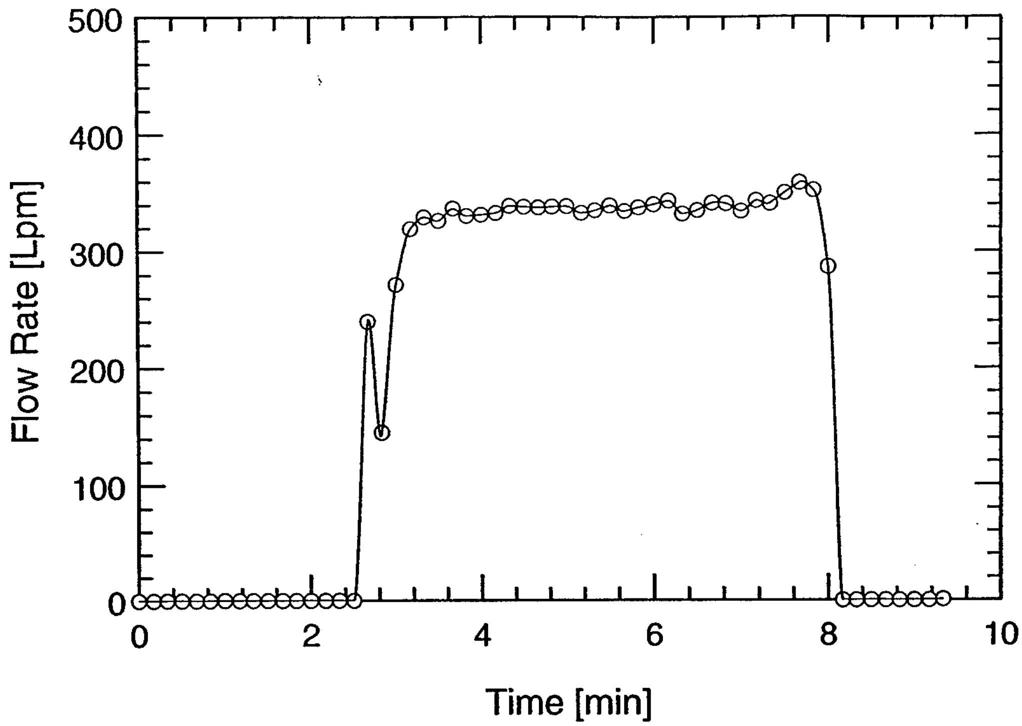


FR 22

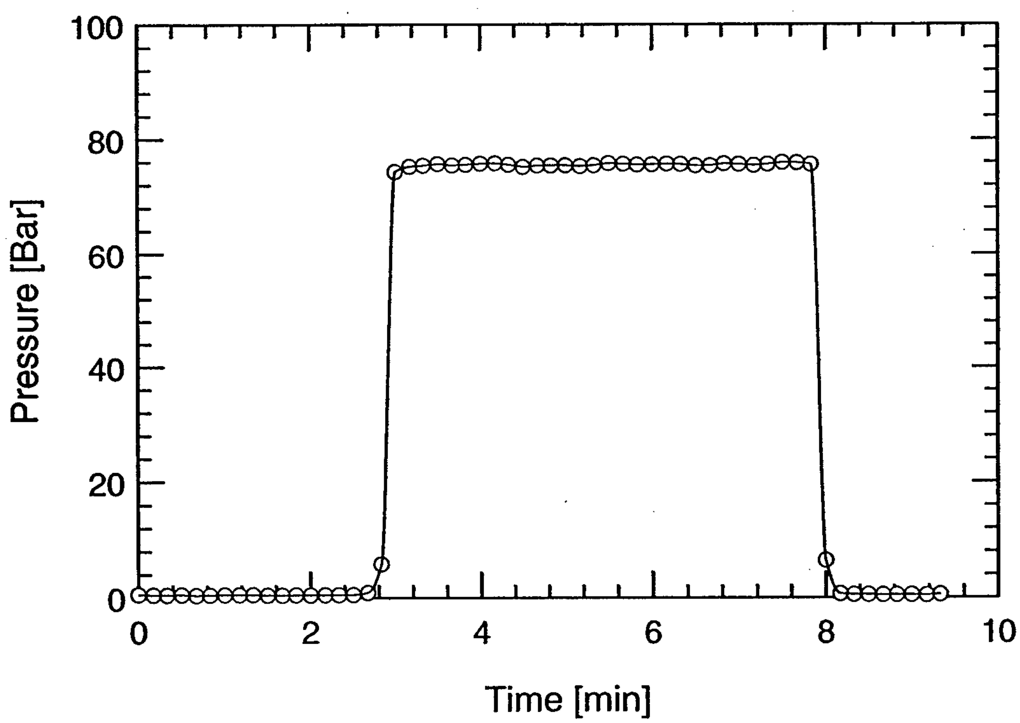


FR 22

Test #21

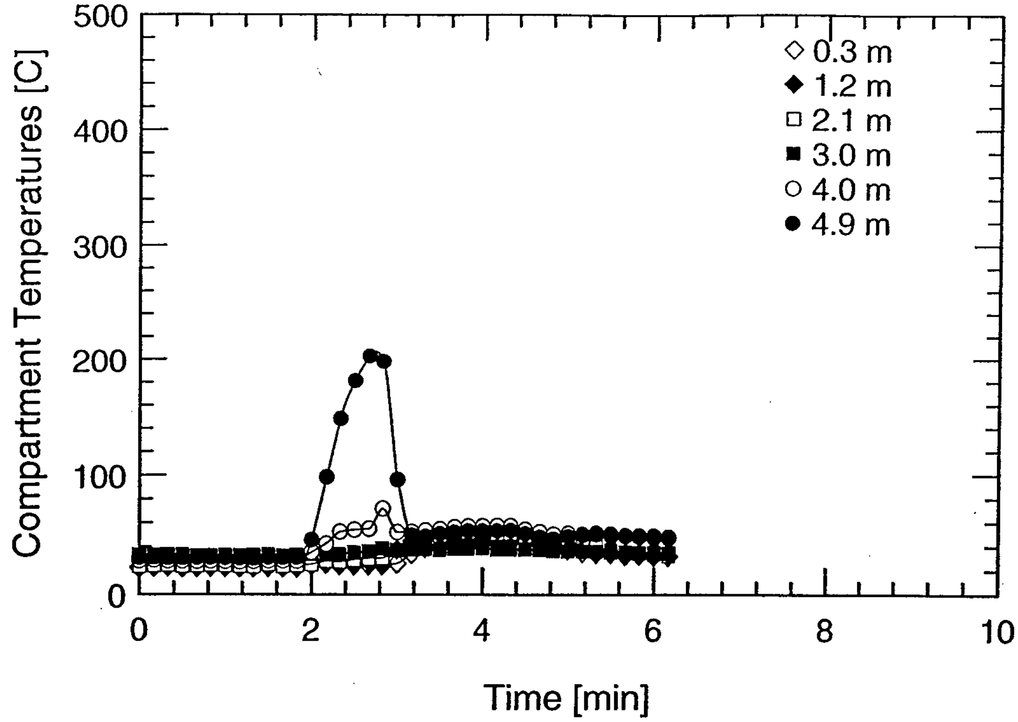


Water Mist System Flow Rate

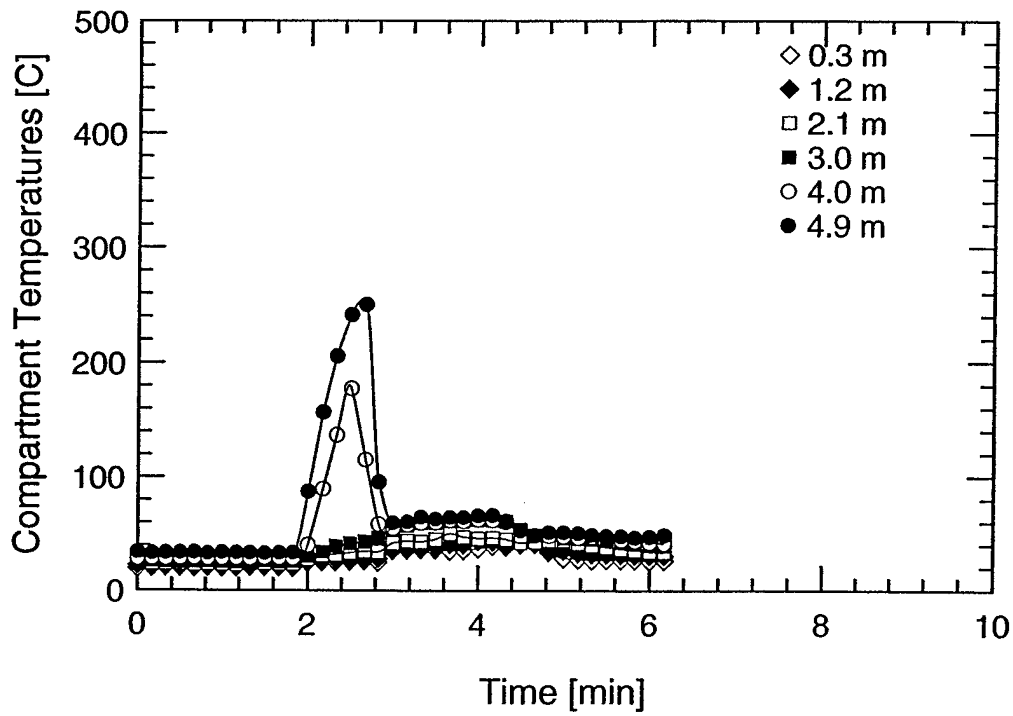


Water Mist System Pressure

Test #21

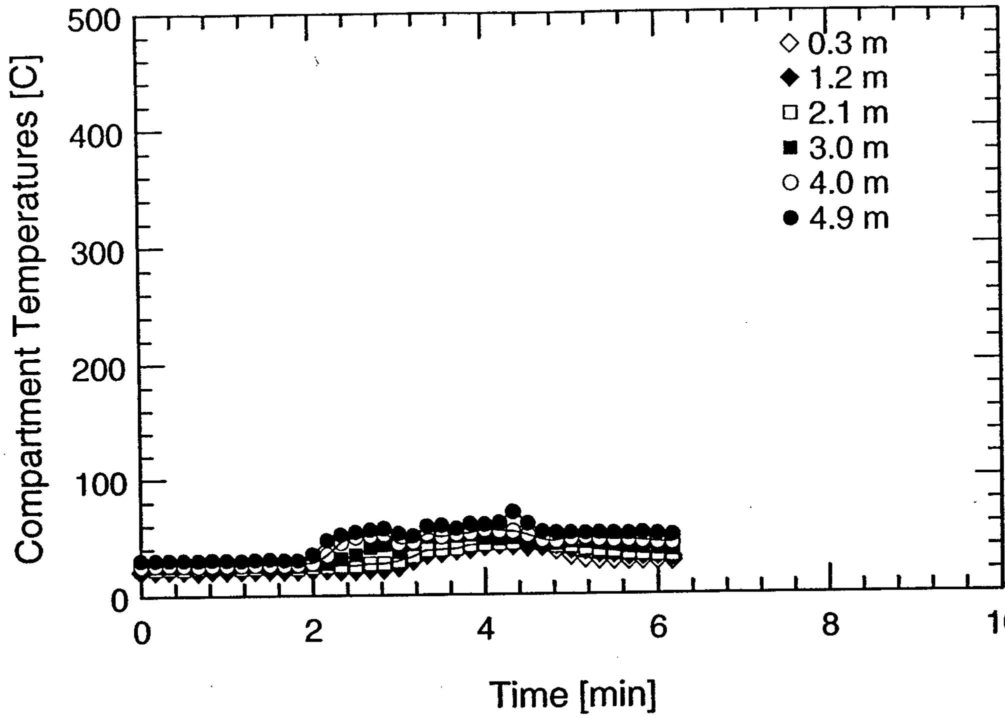


5-22-1

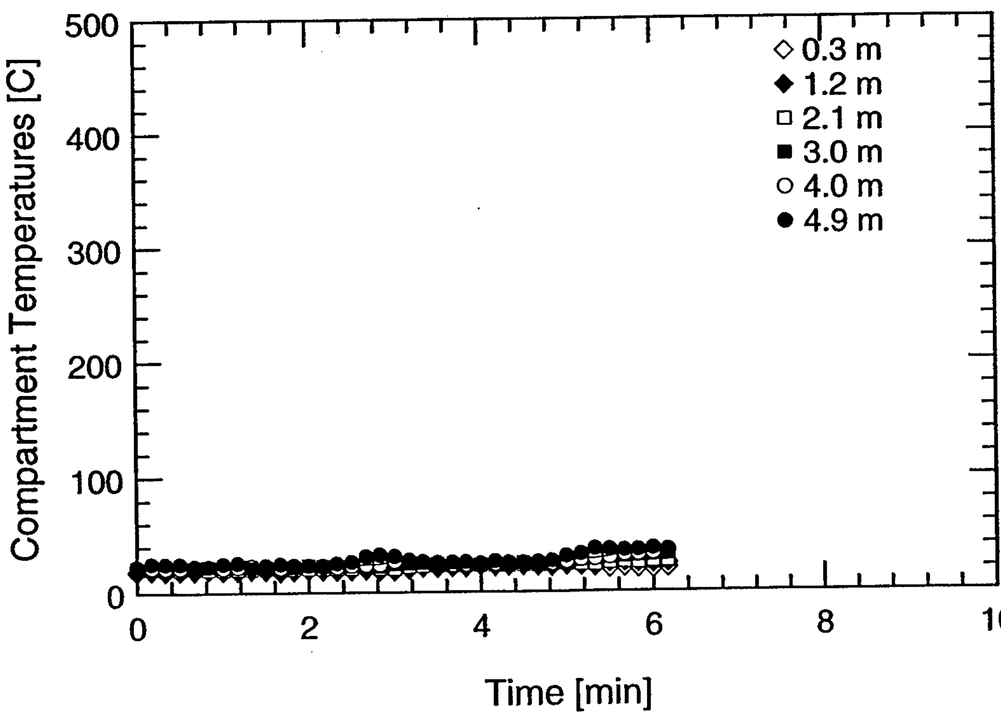


5-27-1

Test #22

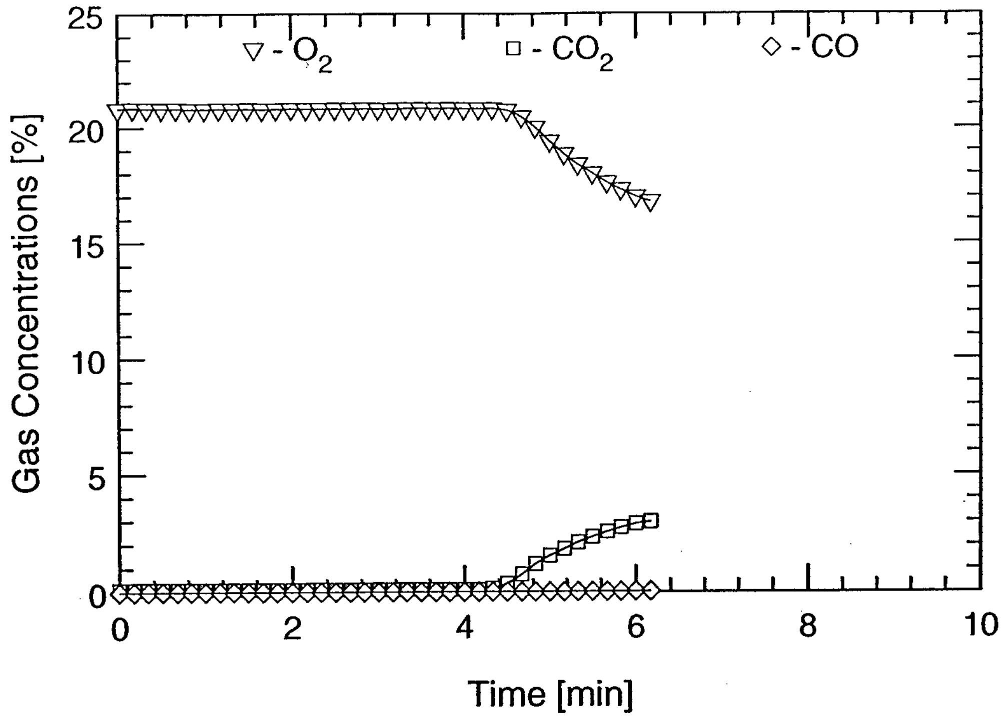


5-27-2

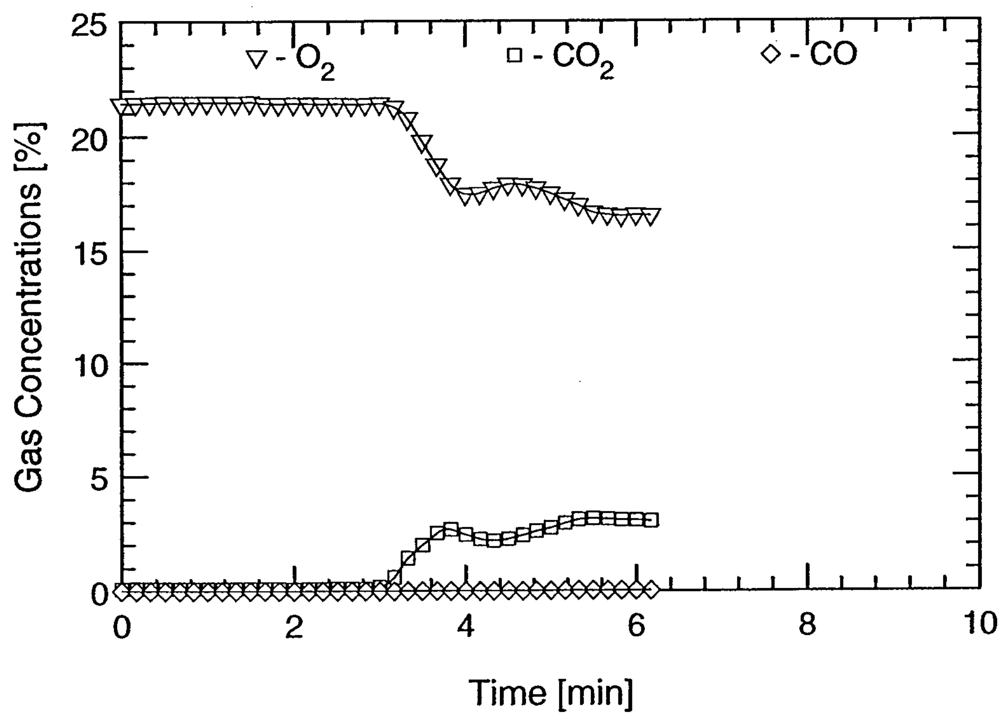


5-35-1

Test #22

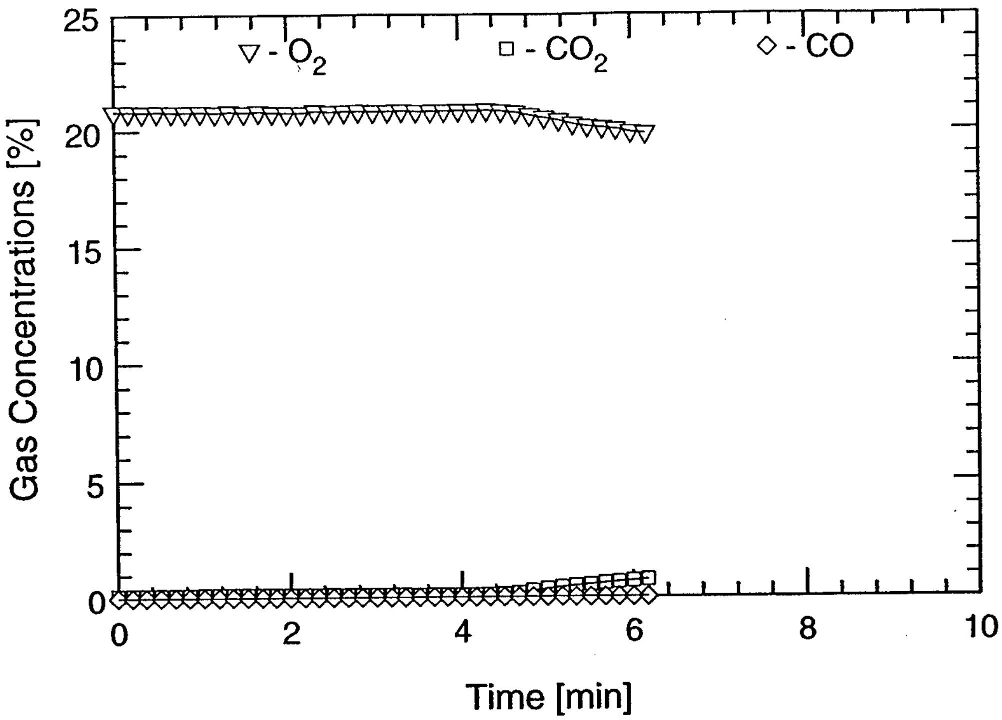


FR 22 - 0.5 m

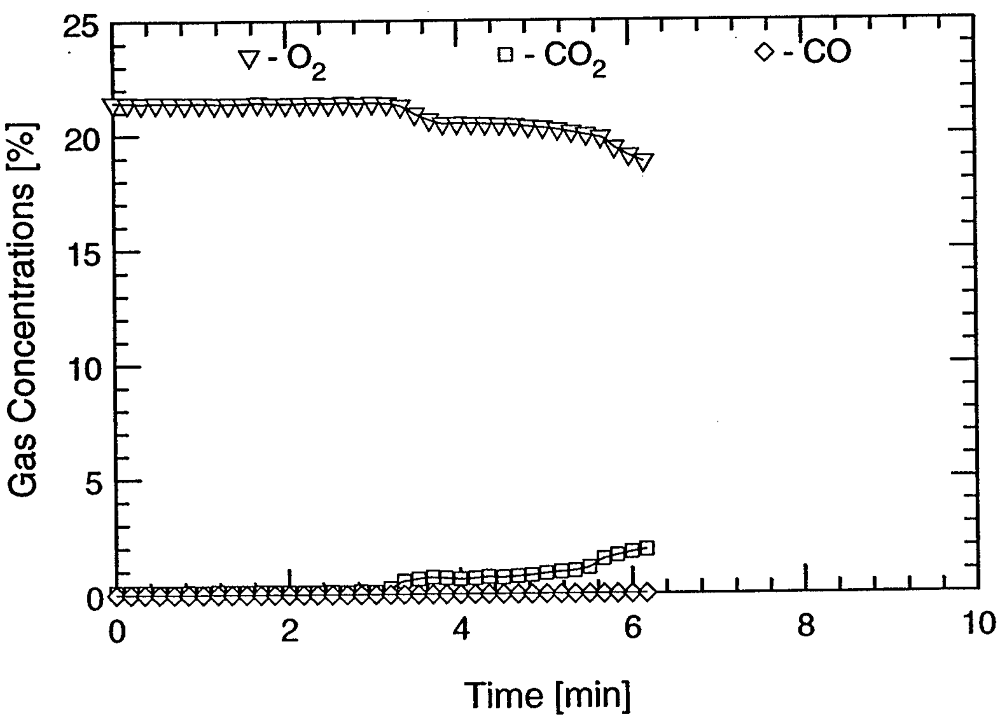


FR 22 - 4.5 m

Test #22

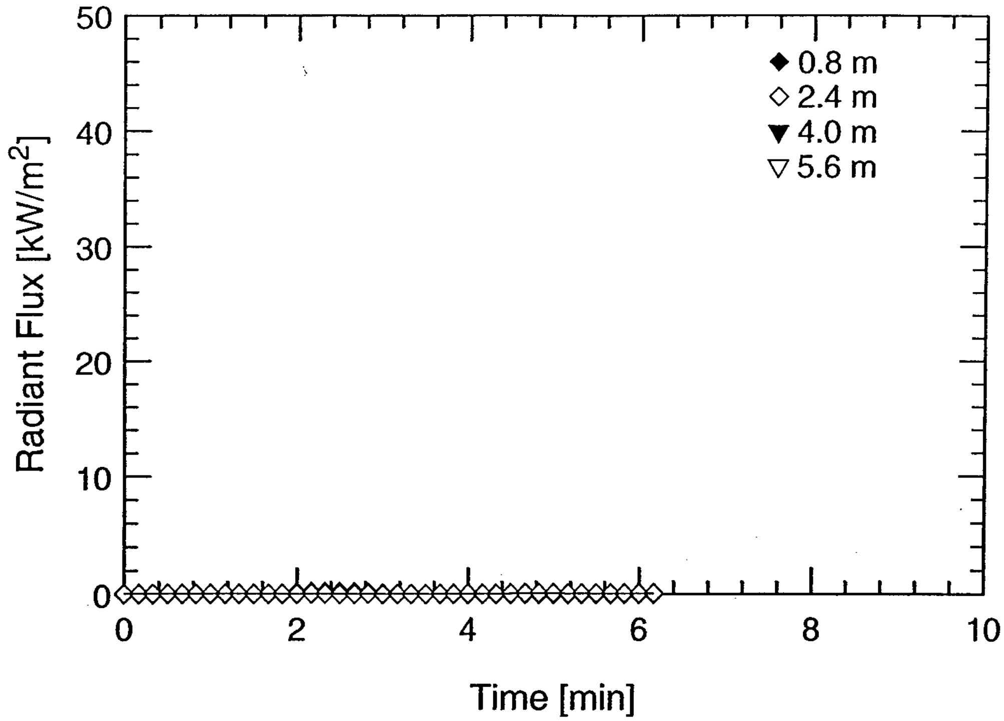


FR 36 - 0.5 m

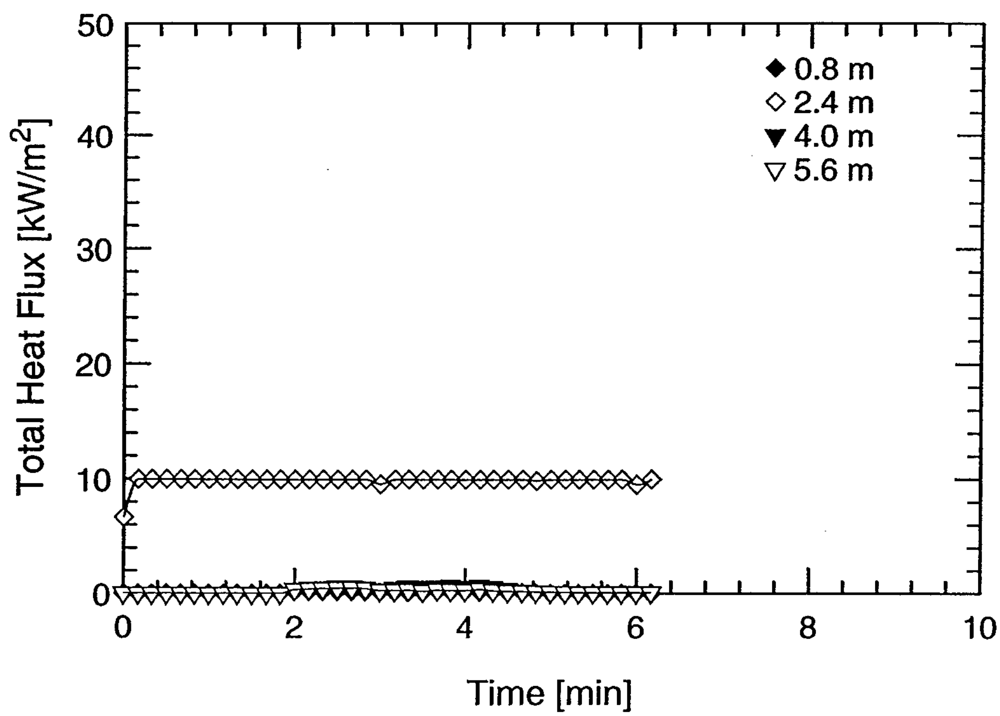


FR 36 - 4.5 m

Test #22

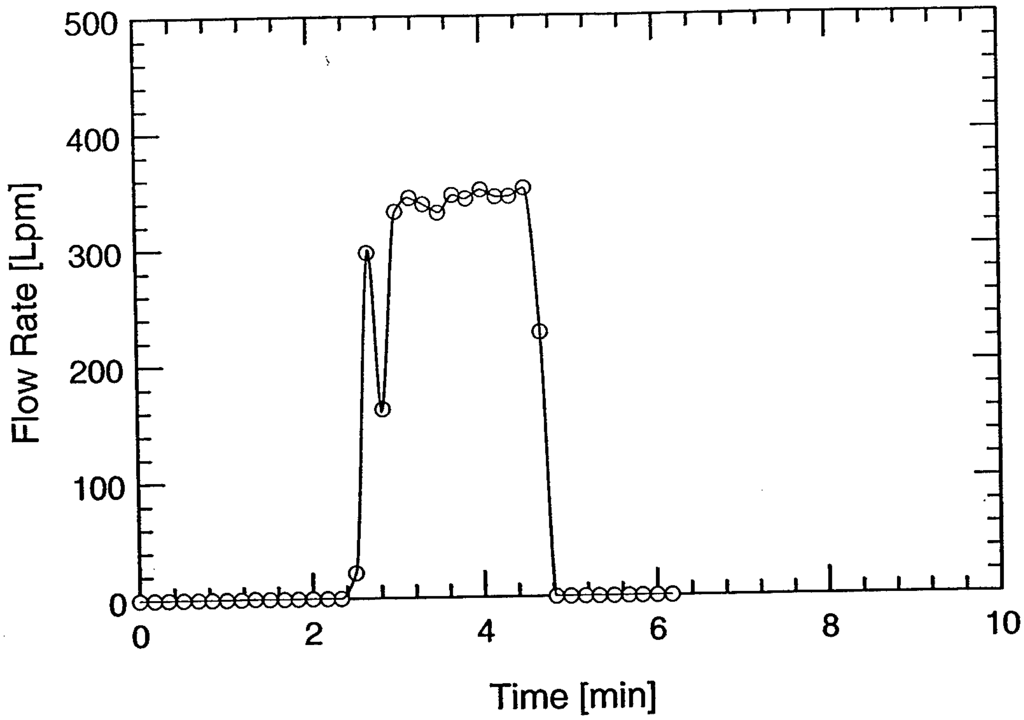


FR 22

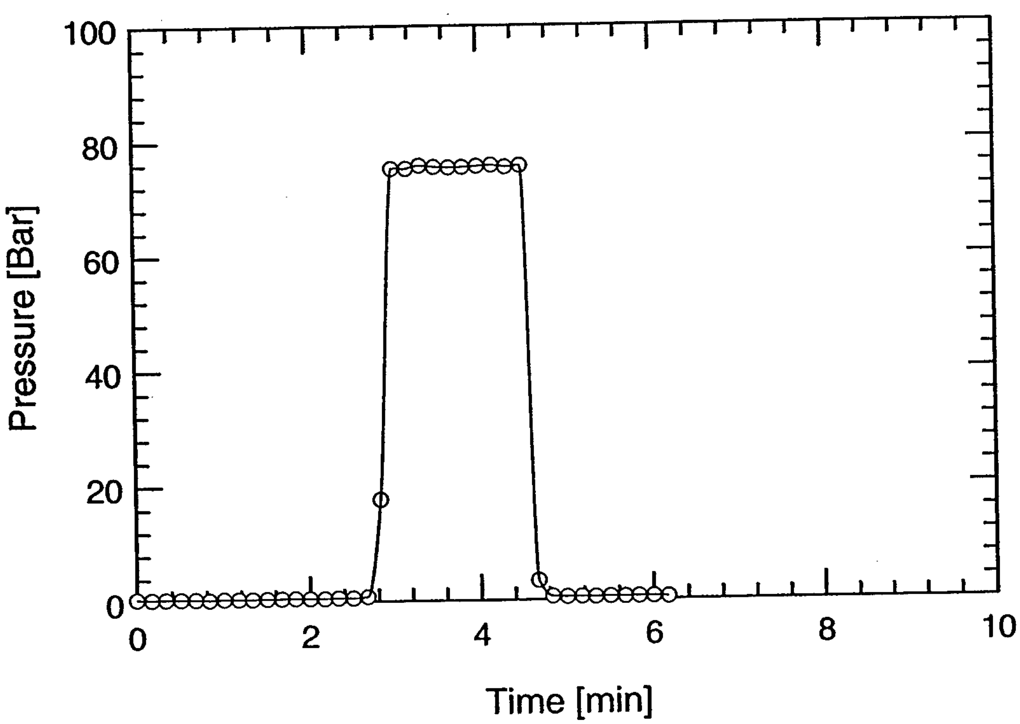


FR 22

Test #22

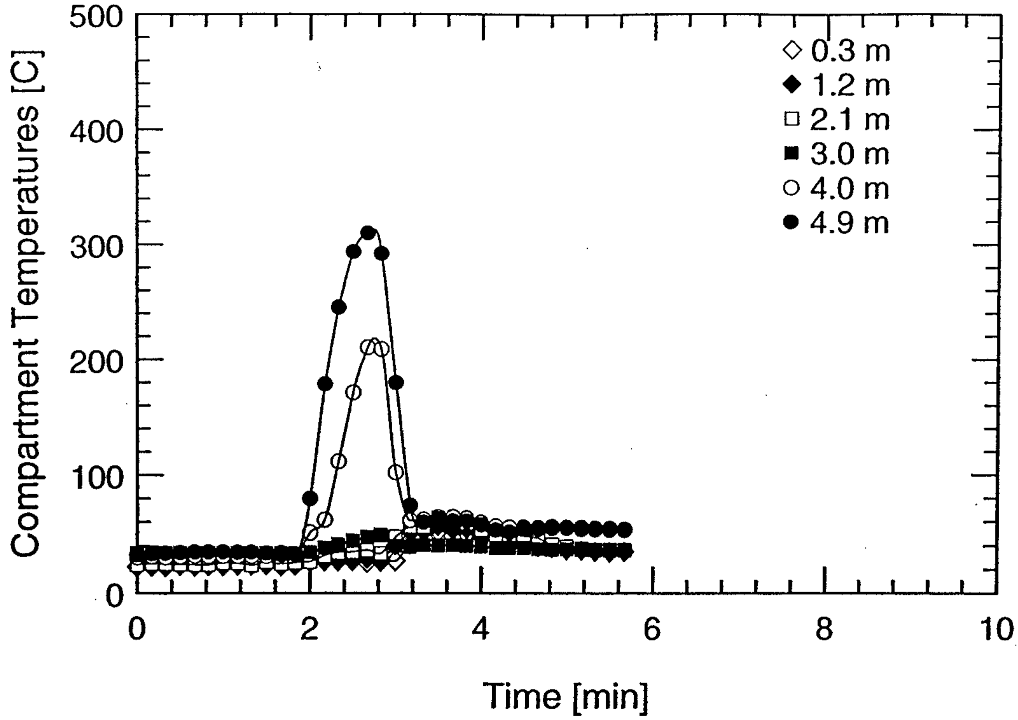


Water Mist System Flow Rate

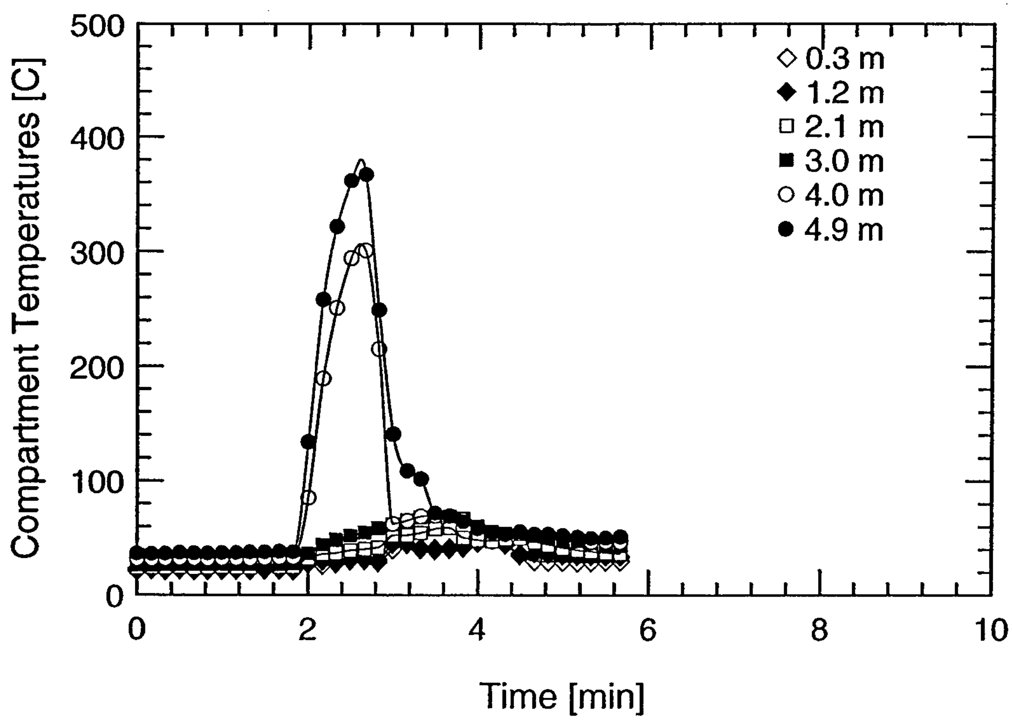


Water Mist System Pressure

Test #22

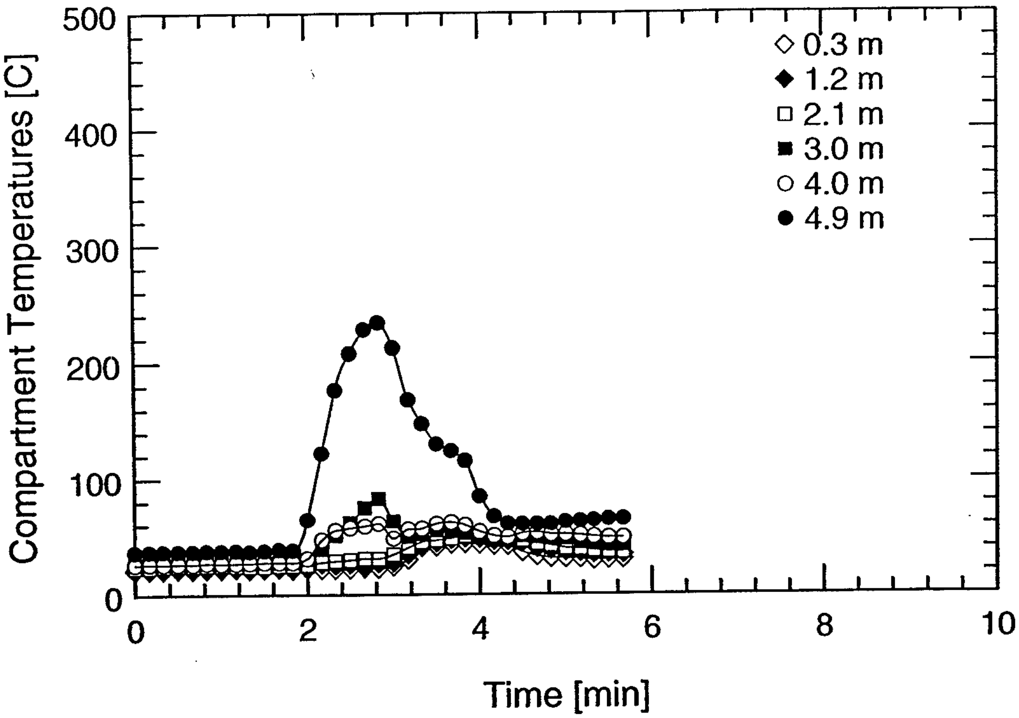


5-22-1

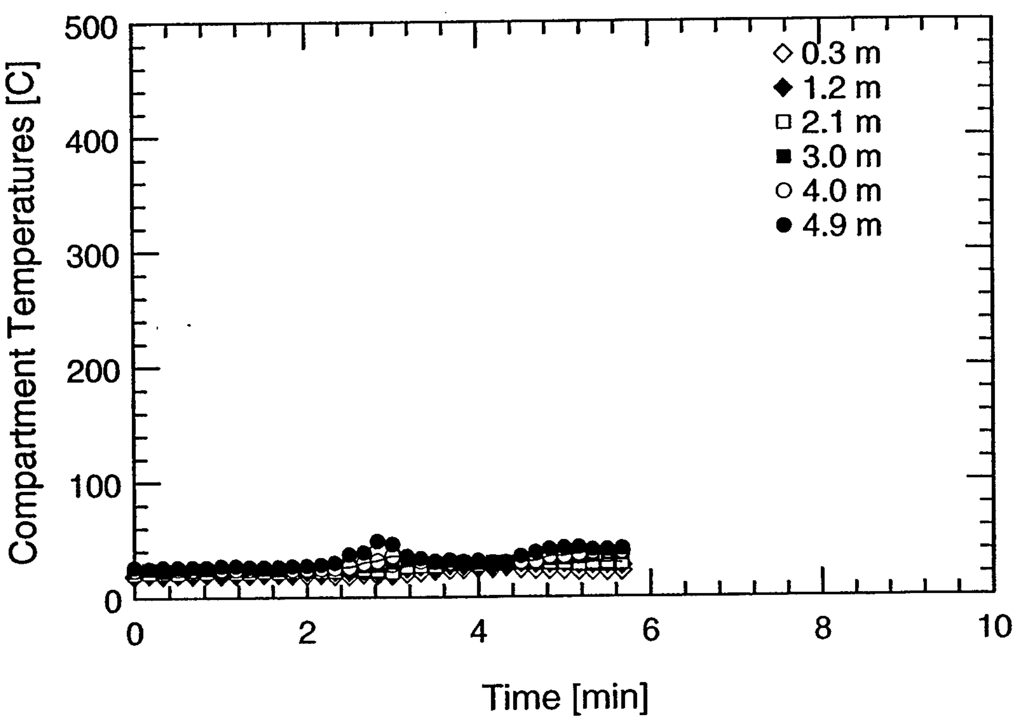


5-27-1

Test #23

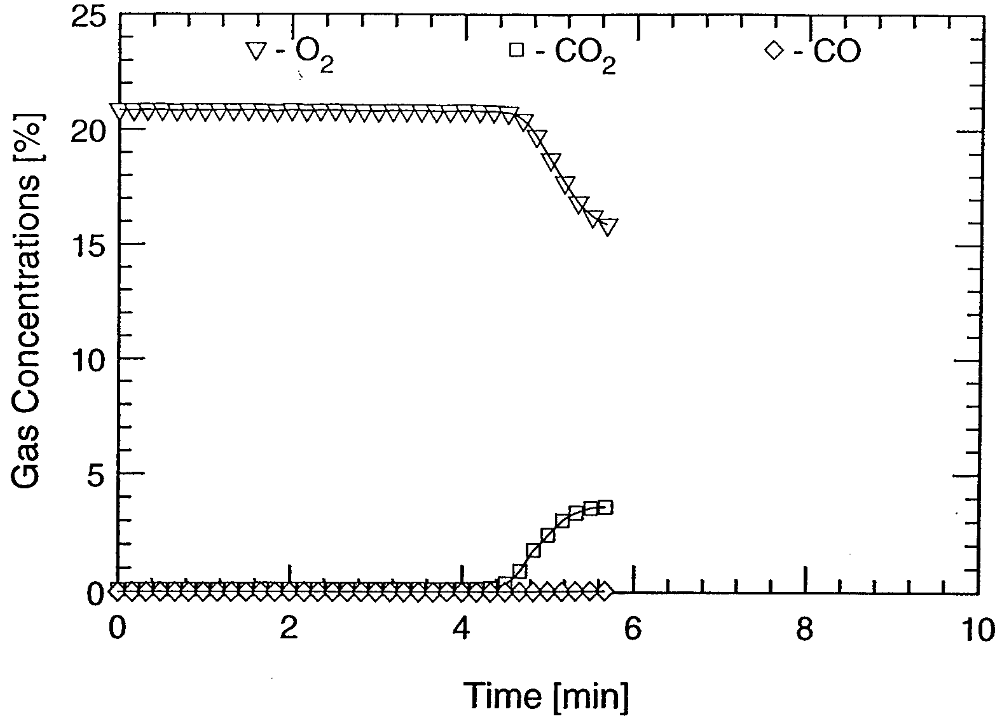


5-27-2

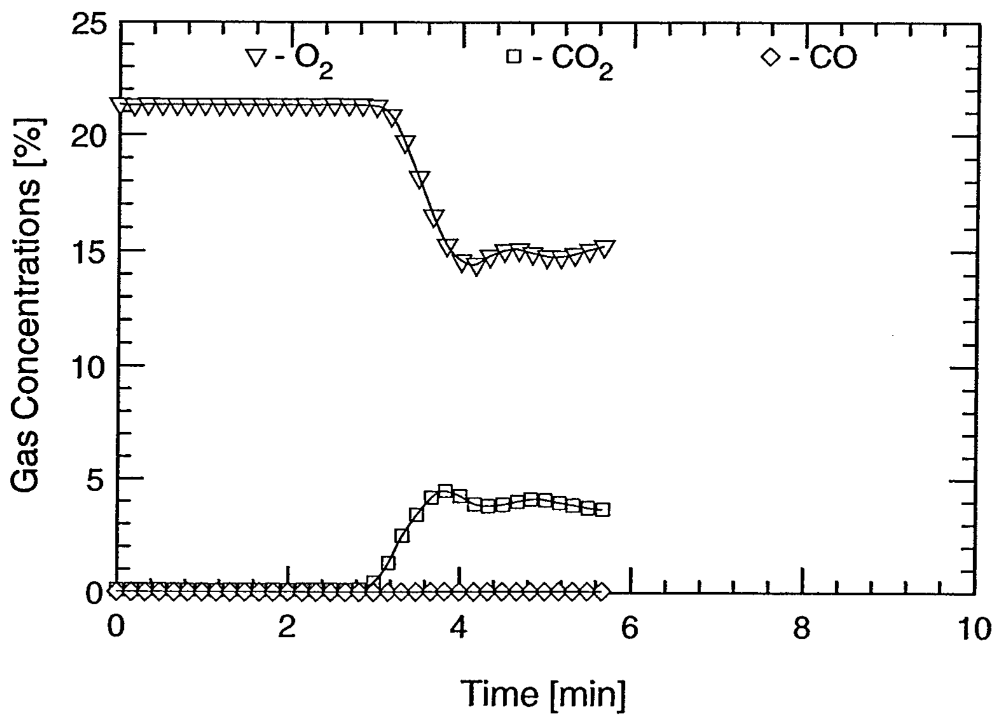


5-35-1

Test #23

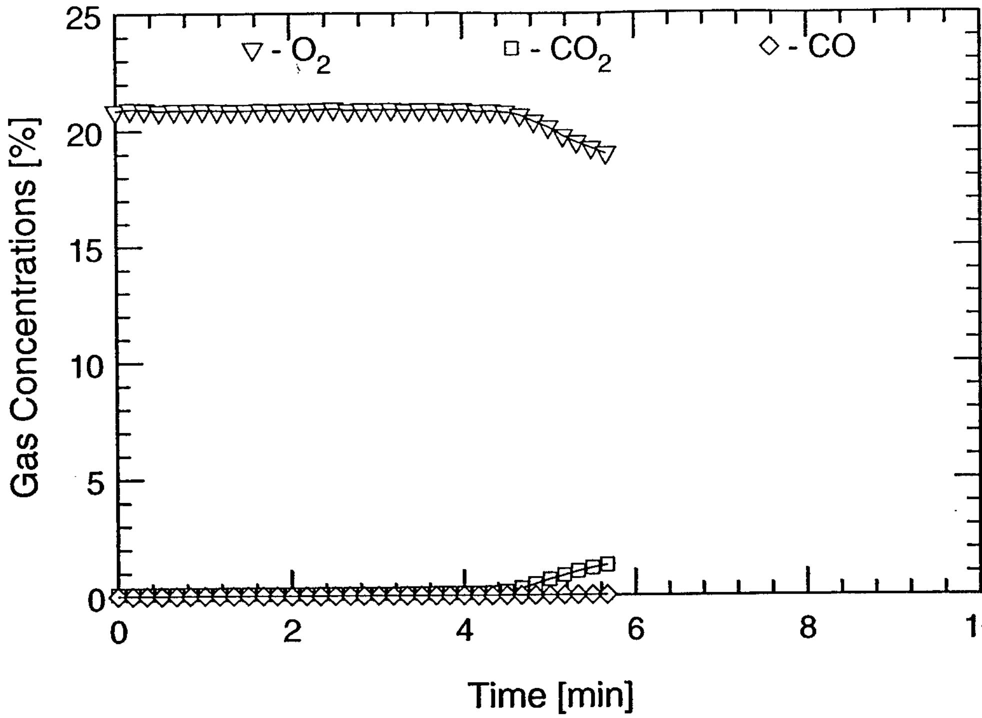


FR 22 - 0.5 m

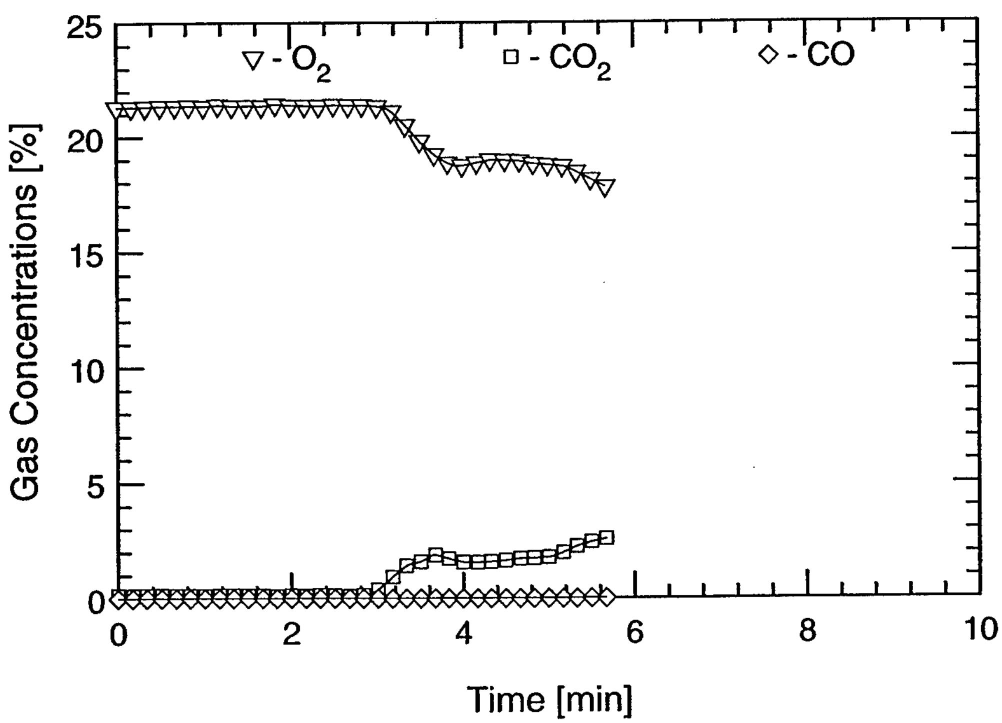


FR 22 - 4.5 m

Test #23

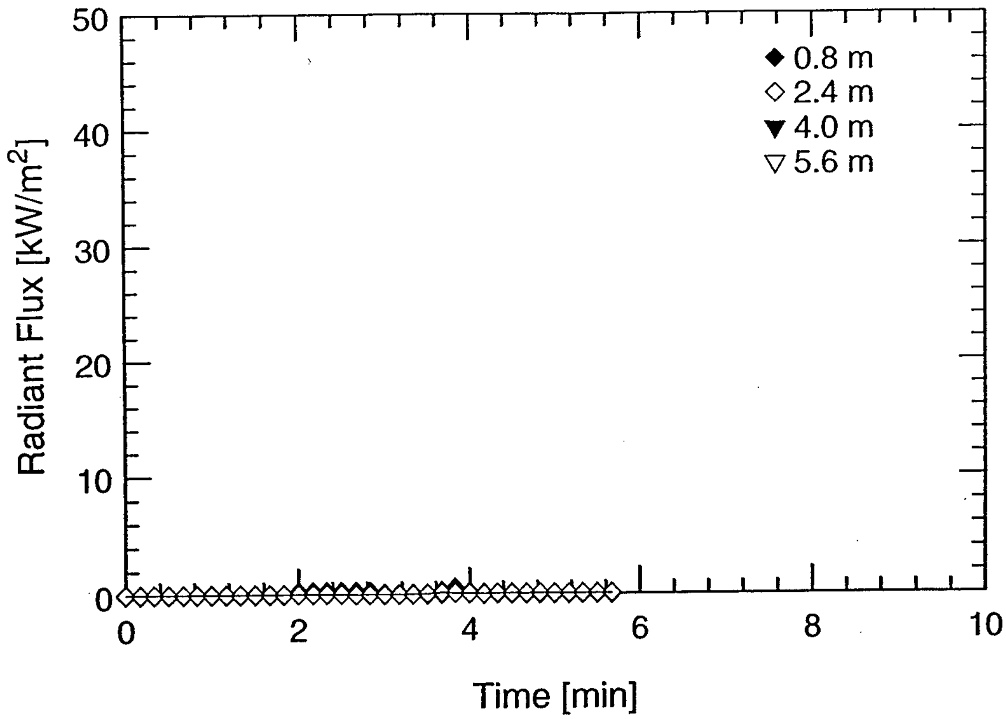


FR 36 - 0.5 m

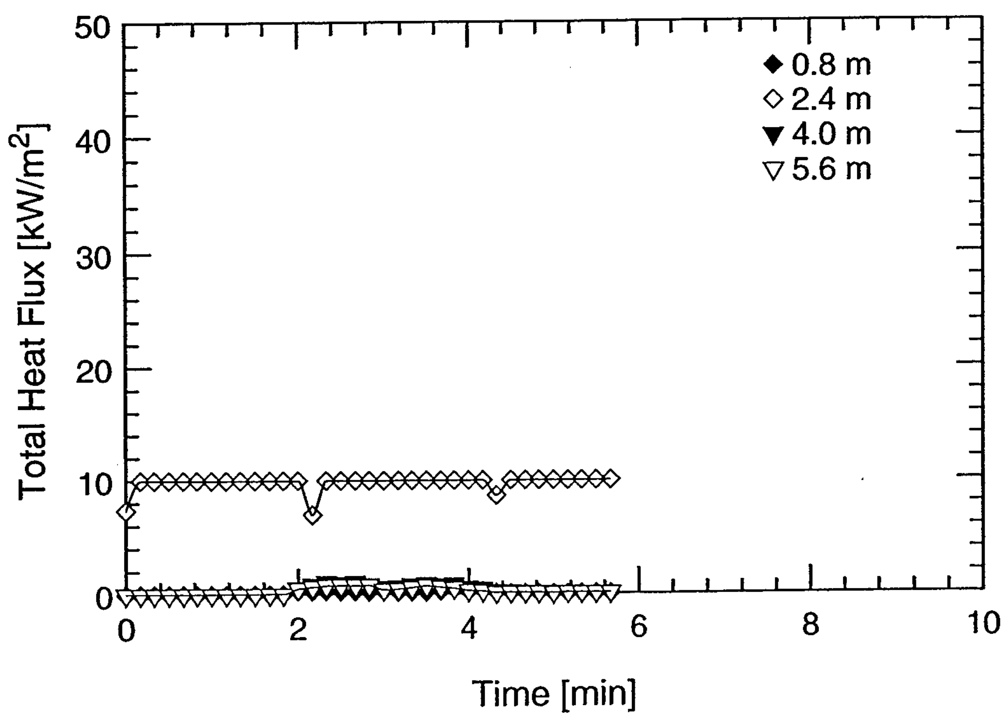


FR 36 - 4.5 m

Test #23

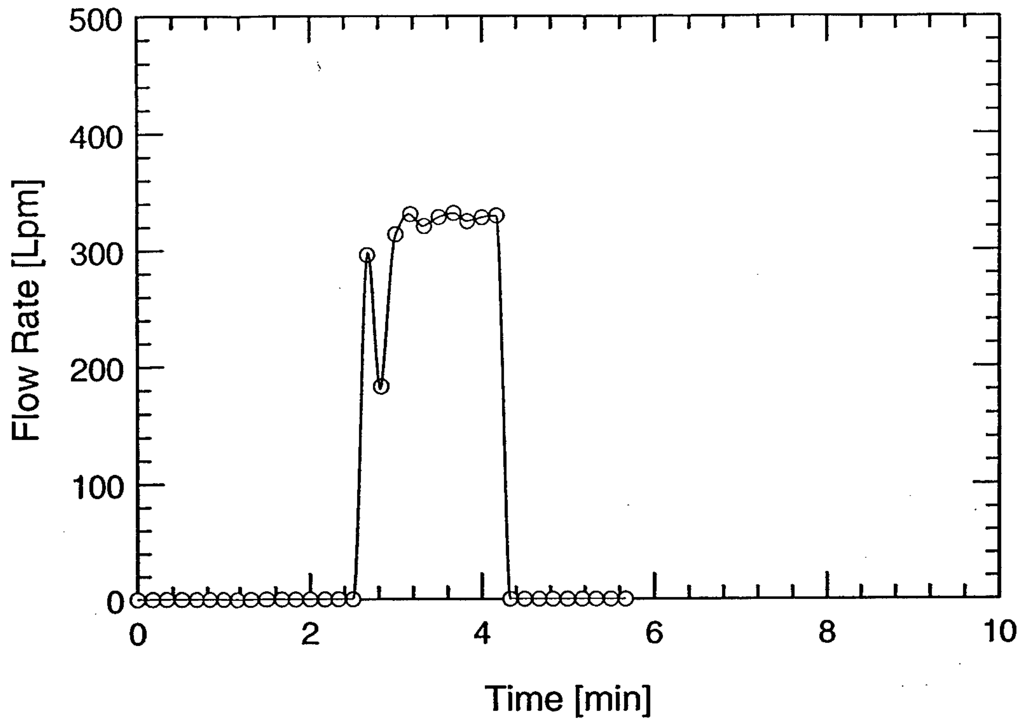


FR 22

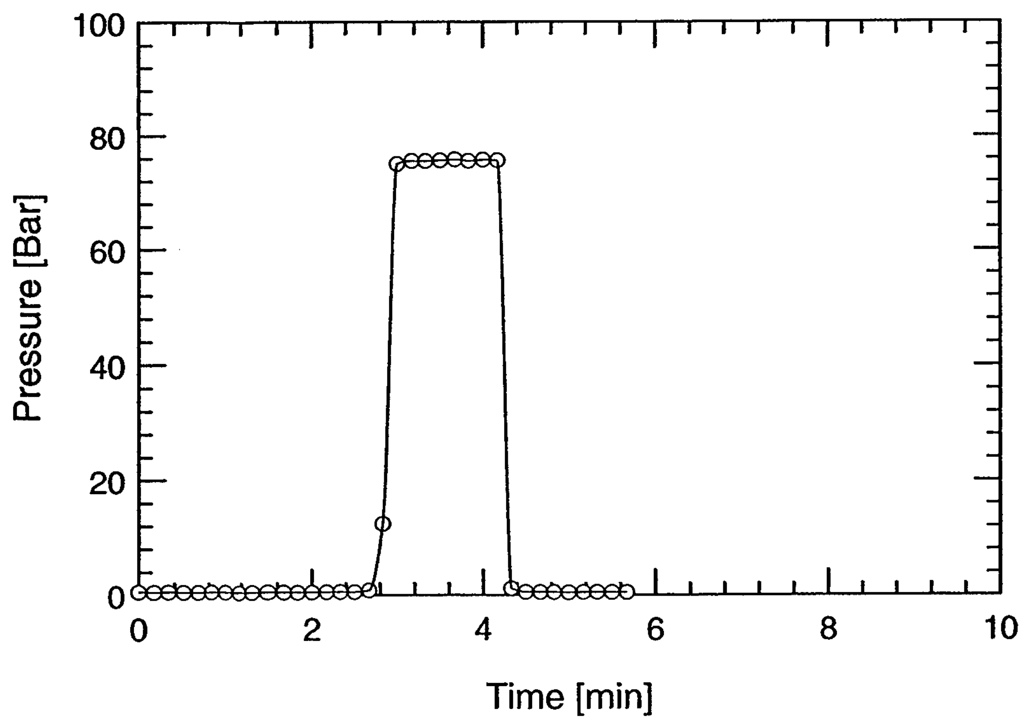


FR 22

Test #23

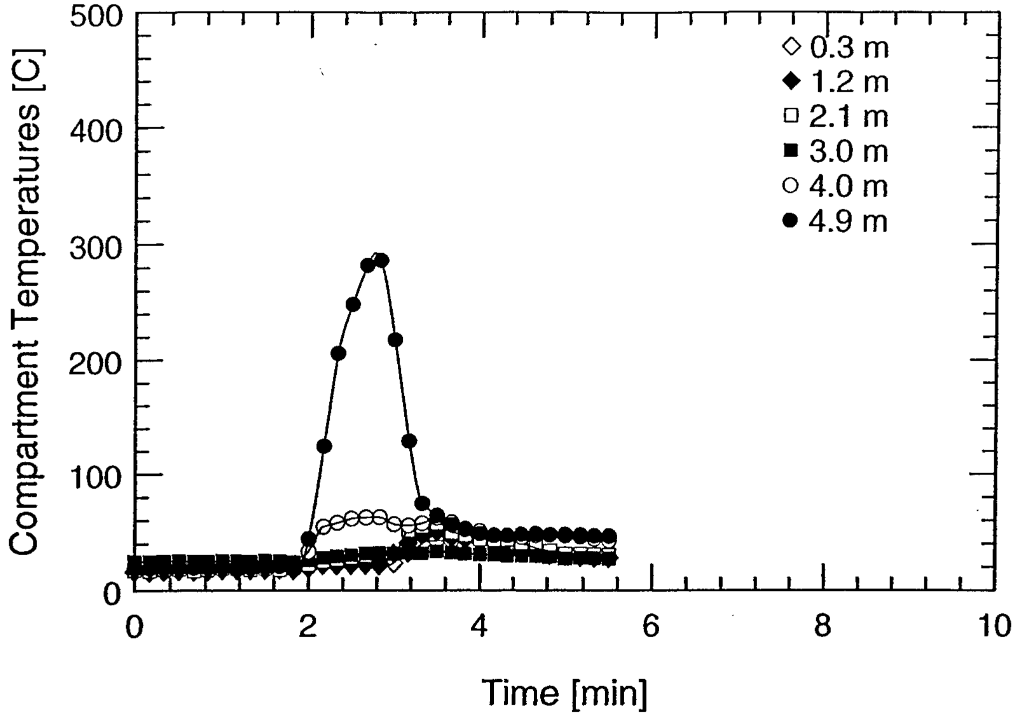


Water Mist System Flow Rate

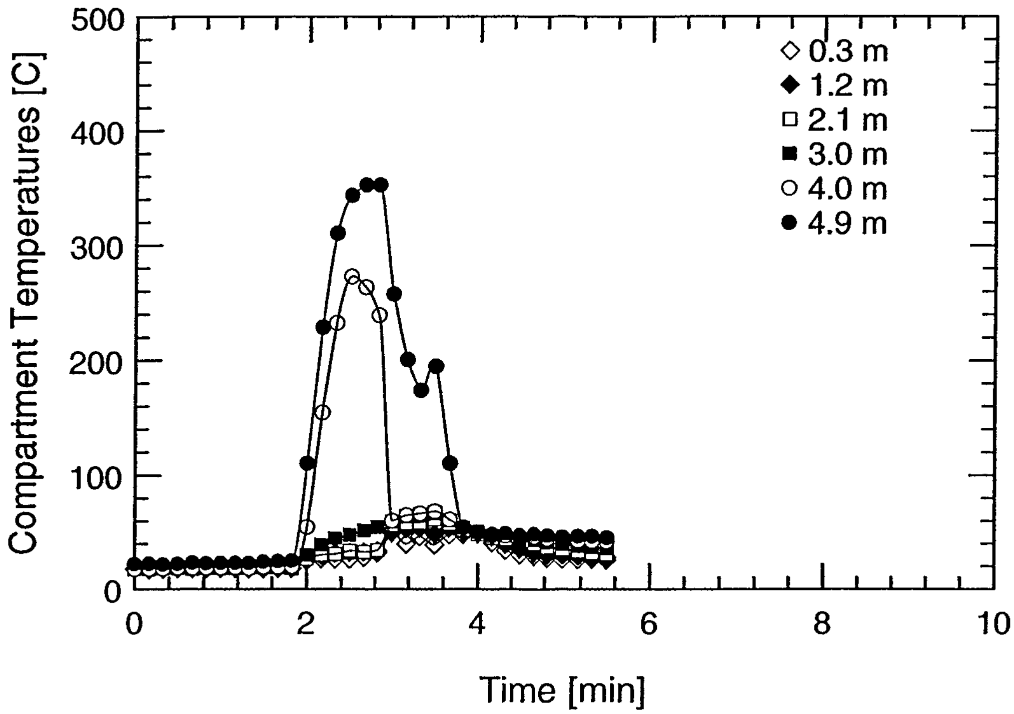


Water Mist System Pressure

Test #23

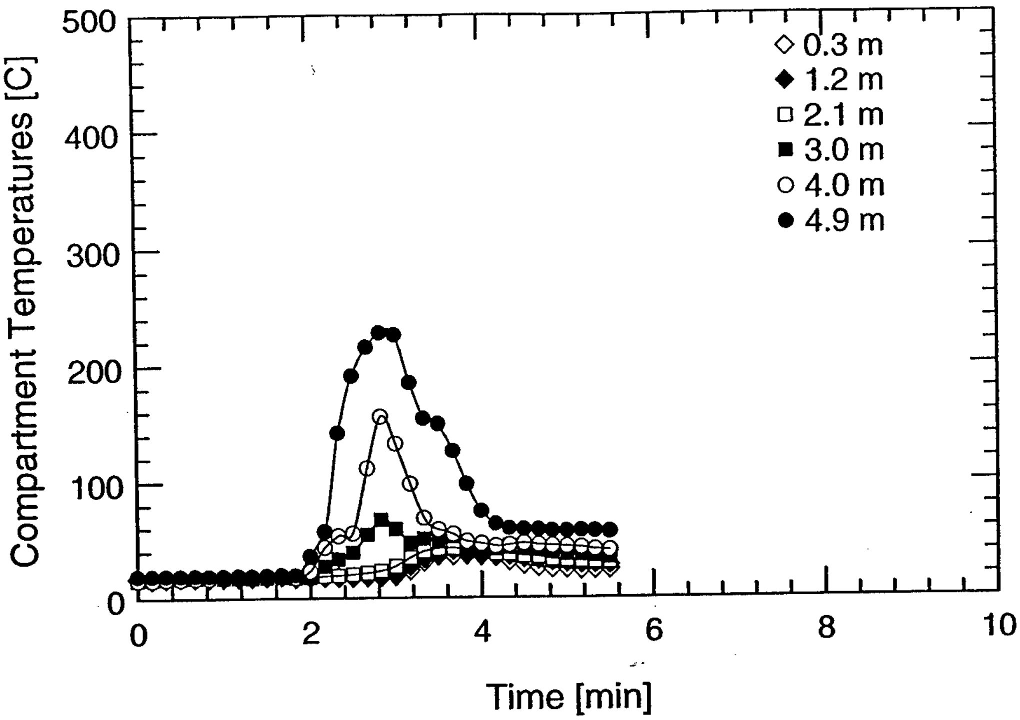


5-22-1

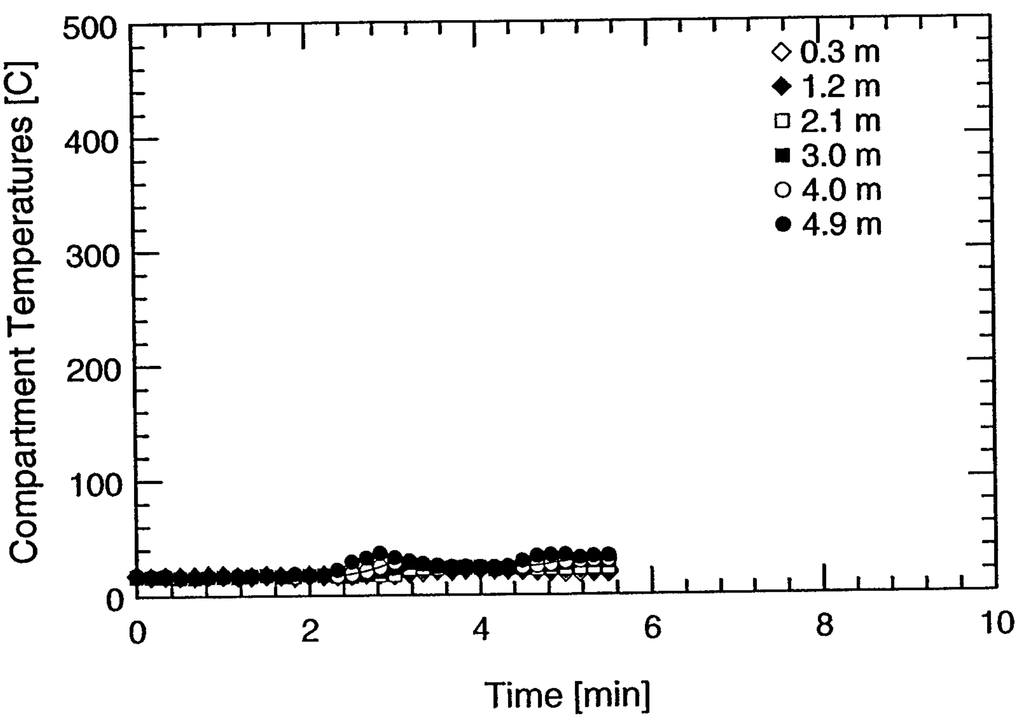


5-27-1

Test #24

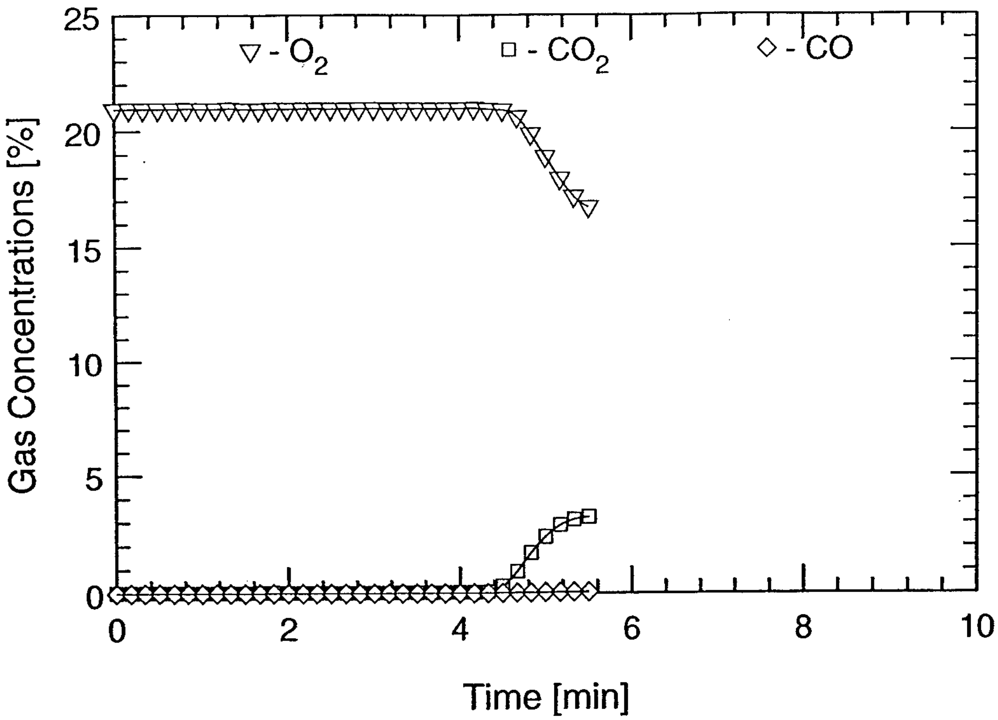


5-27-2

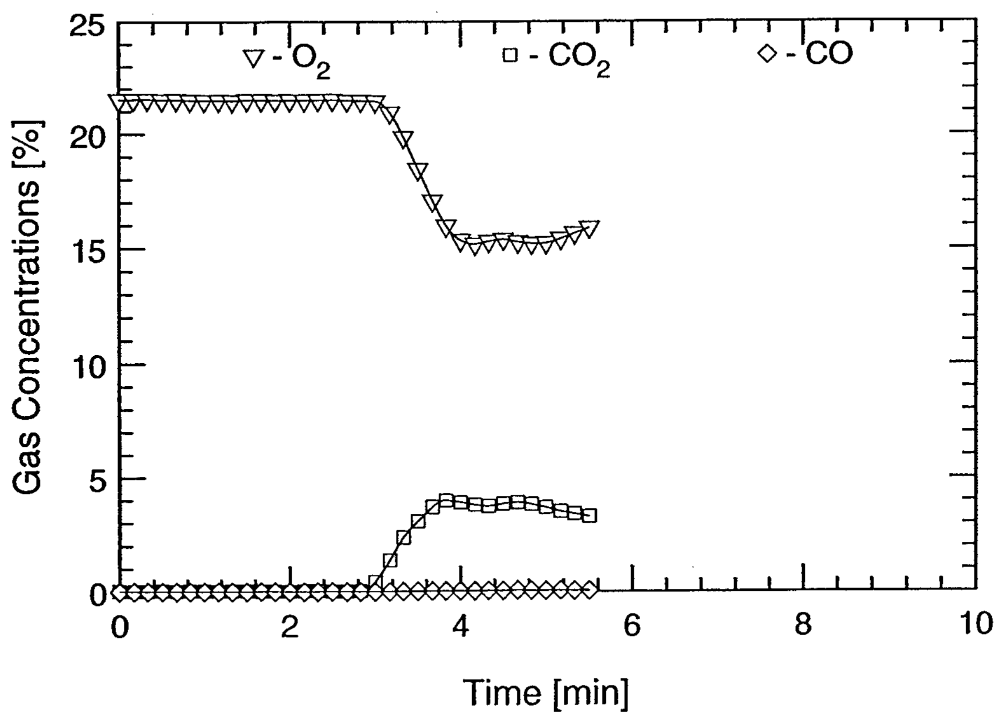


5-35-1

Test #24

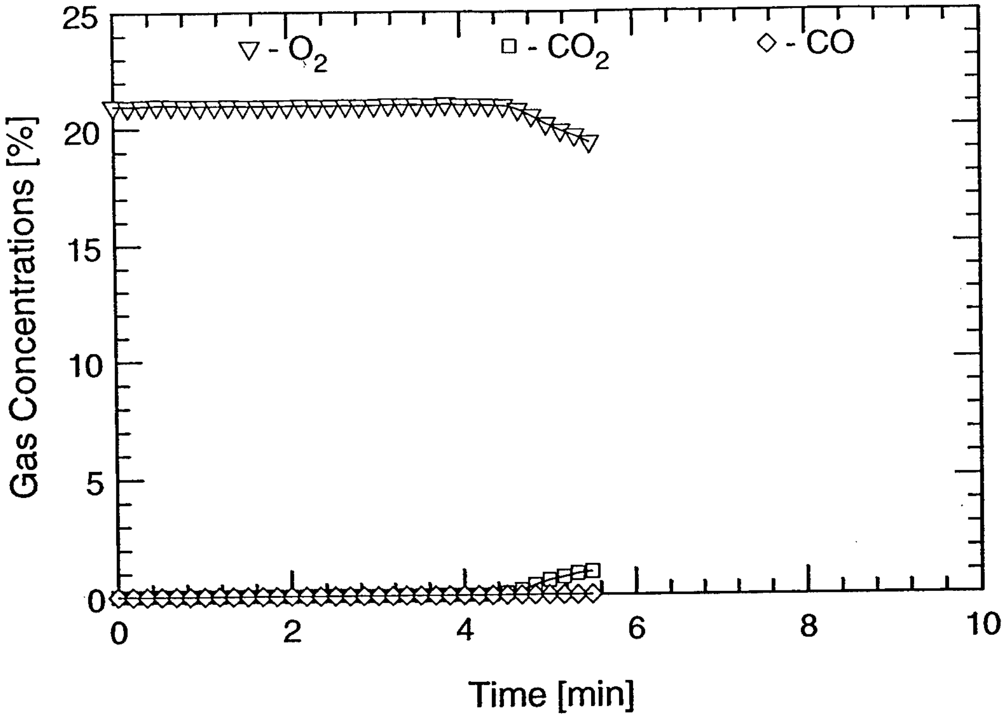


FR 22 - 0.5 m

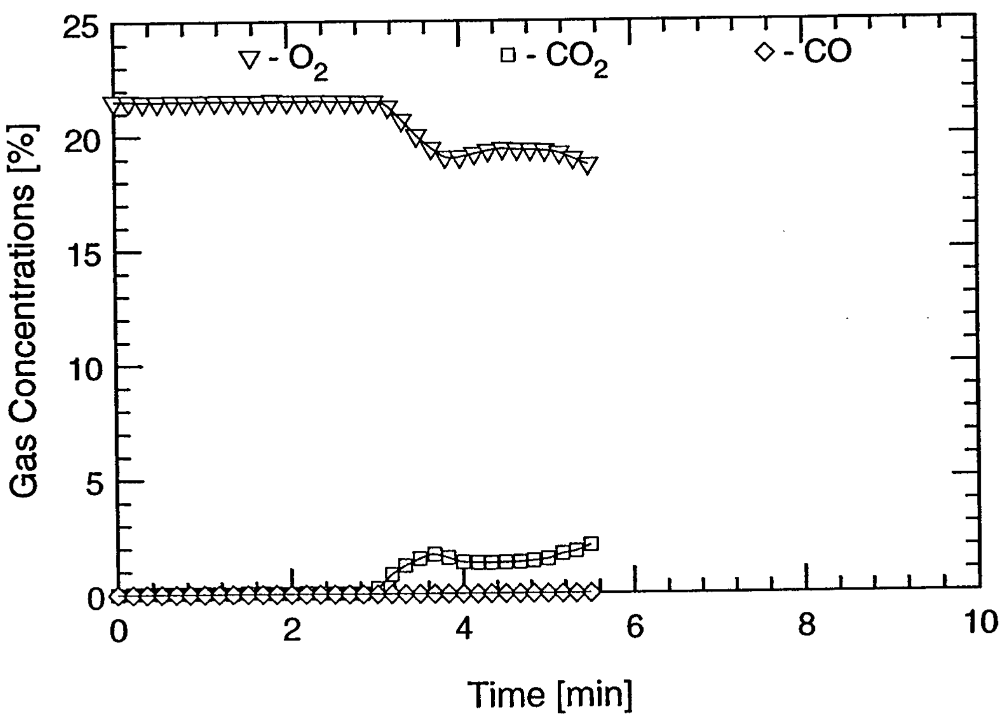


FR 22 - 4.5 m

Test #24

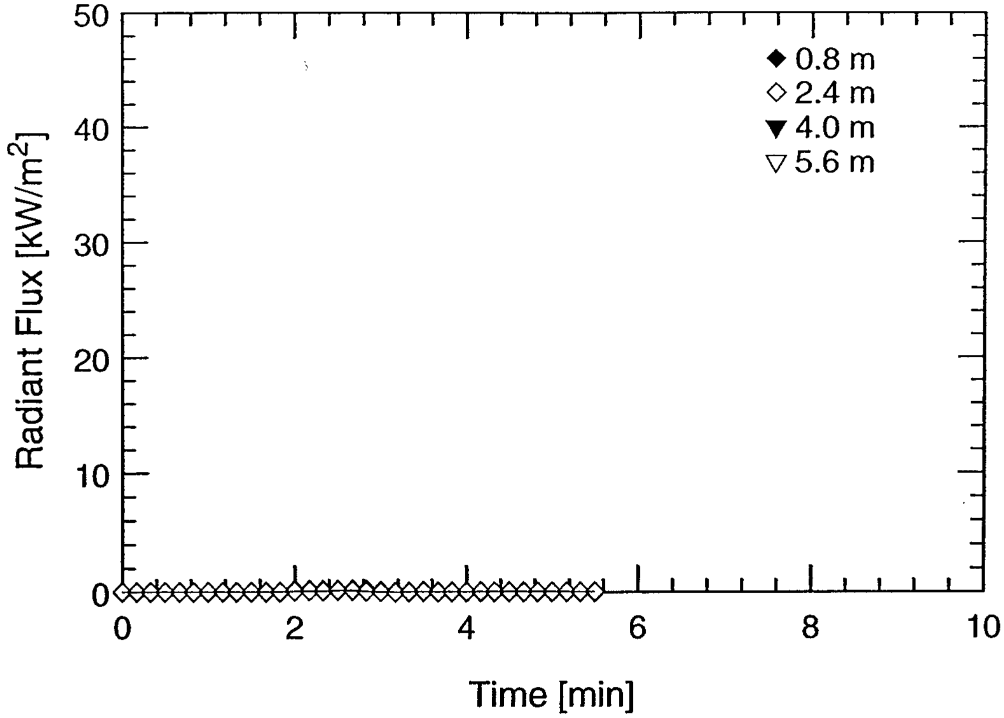


FR 36 - 0.5 m

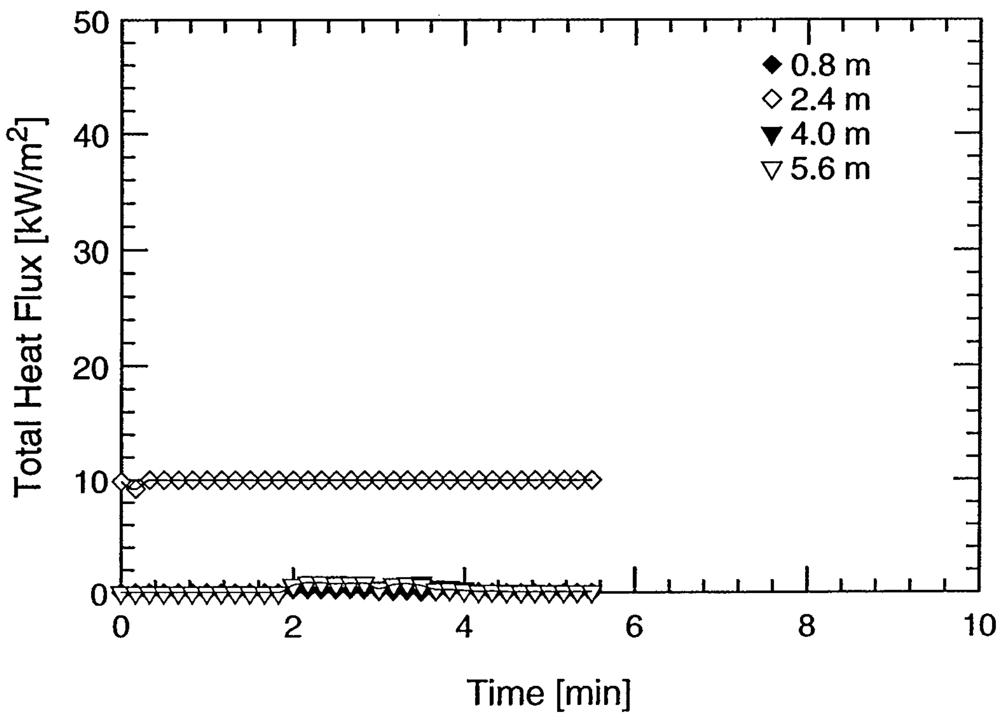


FR 36 - 4.5 m

Test #24

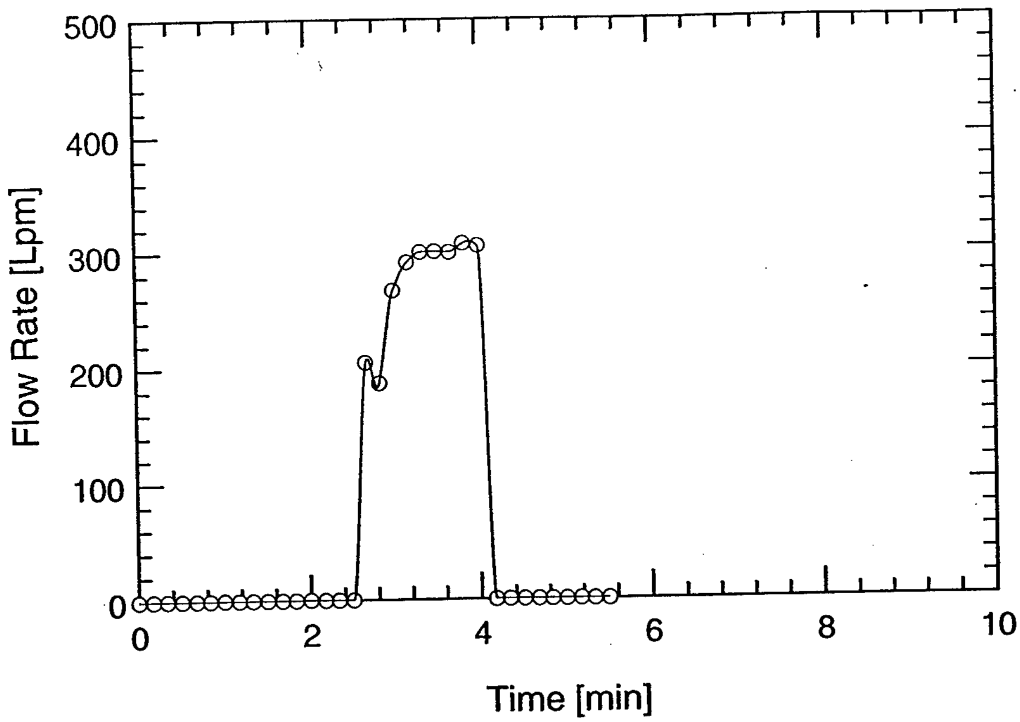


FR 22

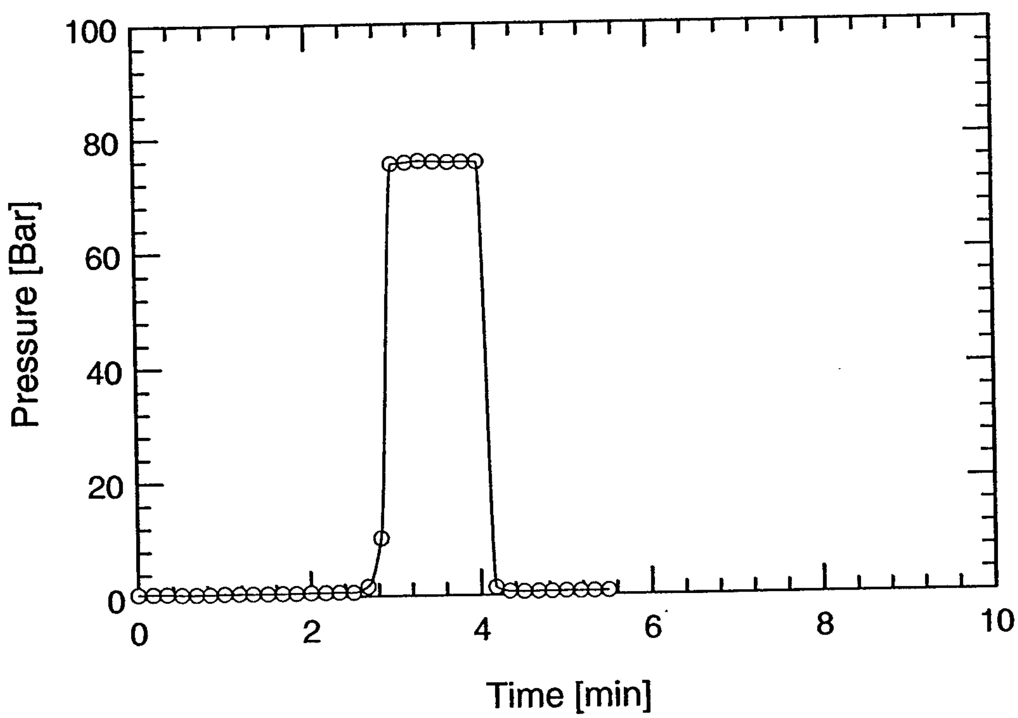


FR 22

Test #24

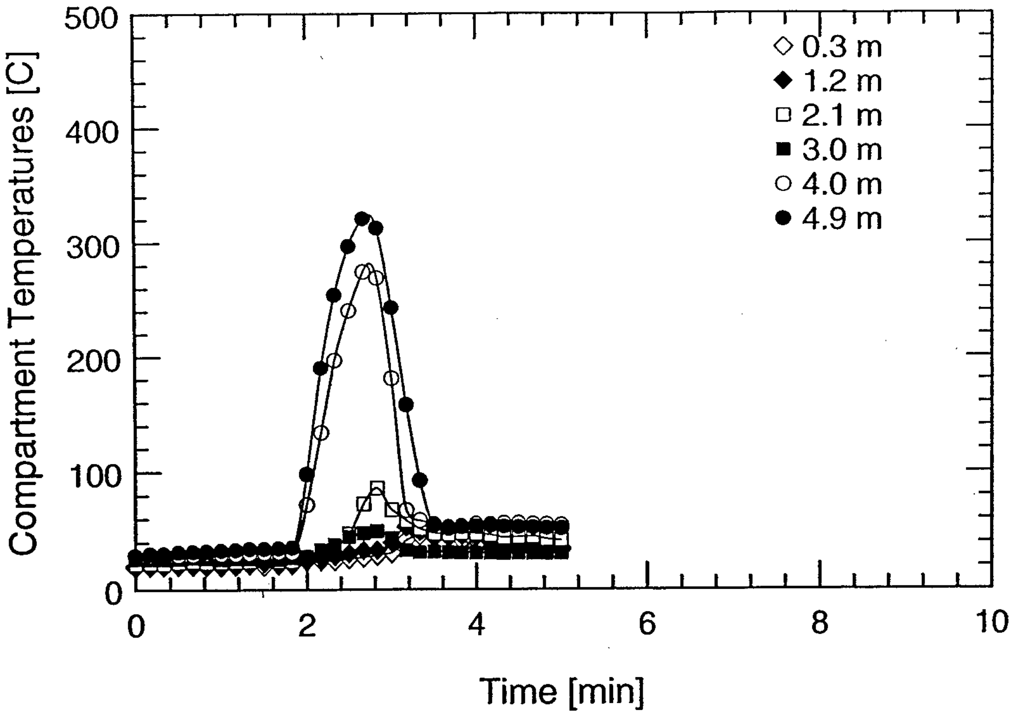


Water Mist System Flow Rate

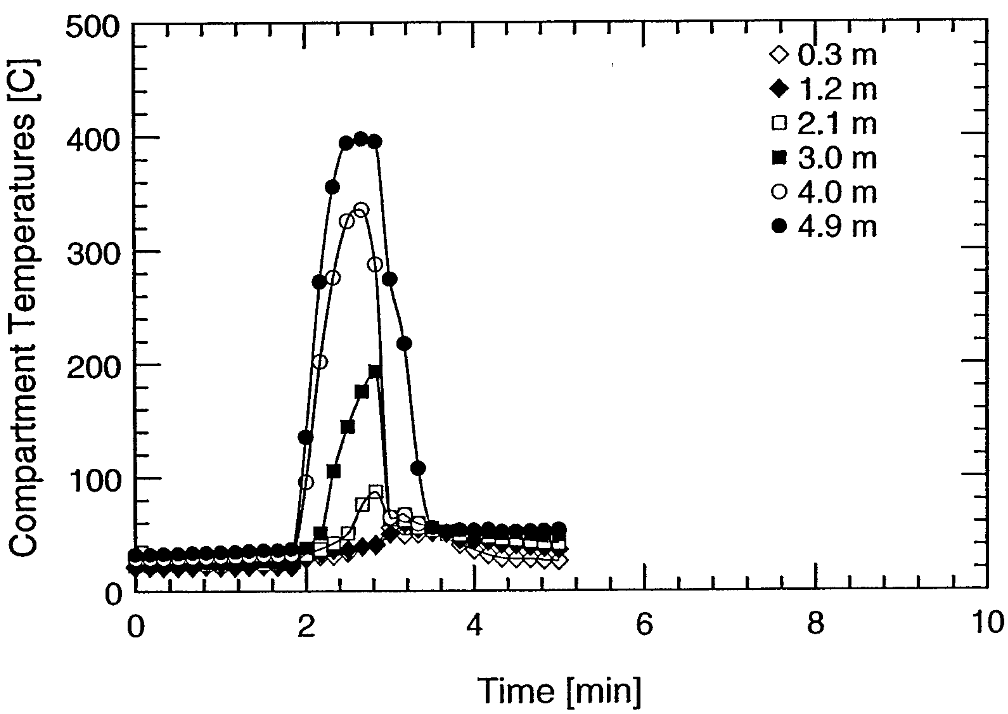


Water Mist System Pressure

Test #24

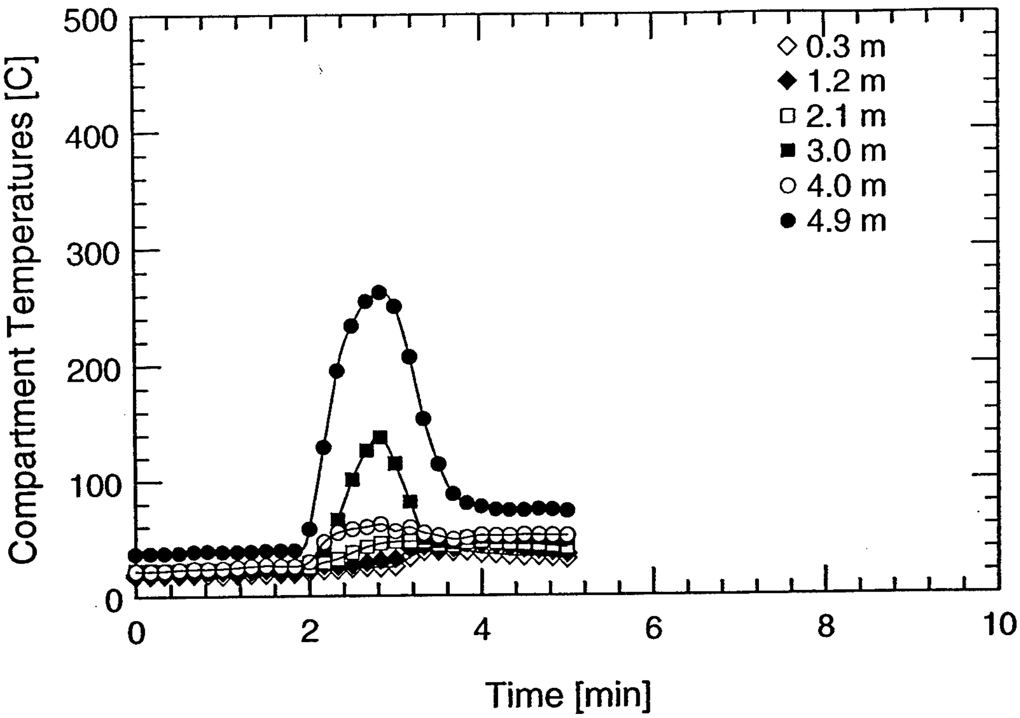


5-22-1

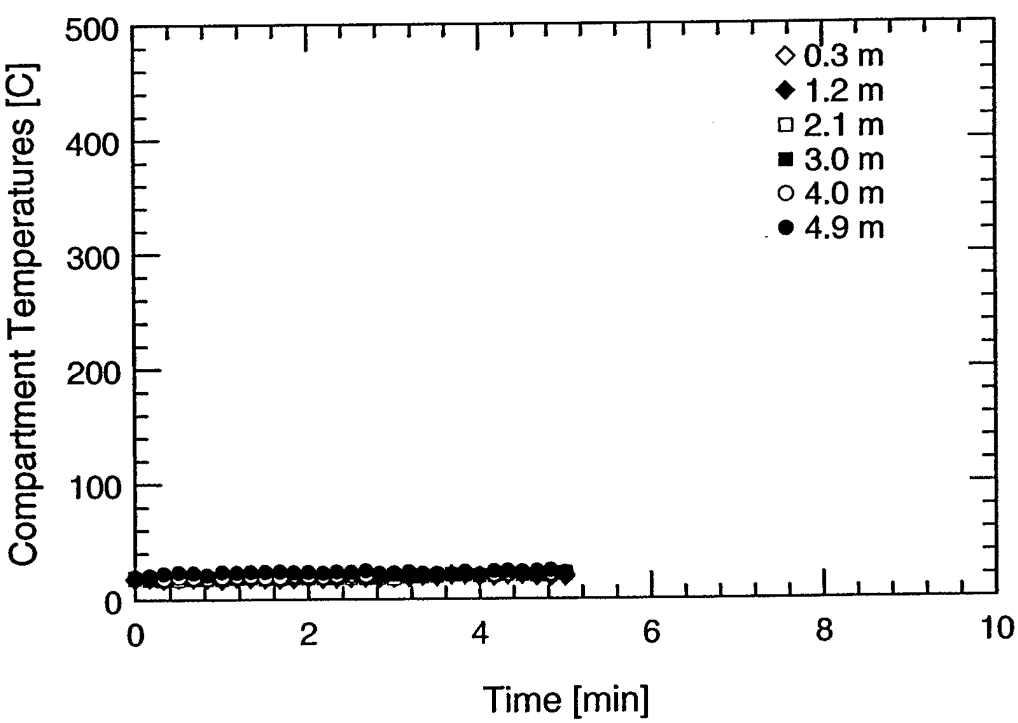


5-27-1

Test #25

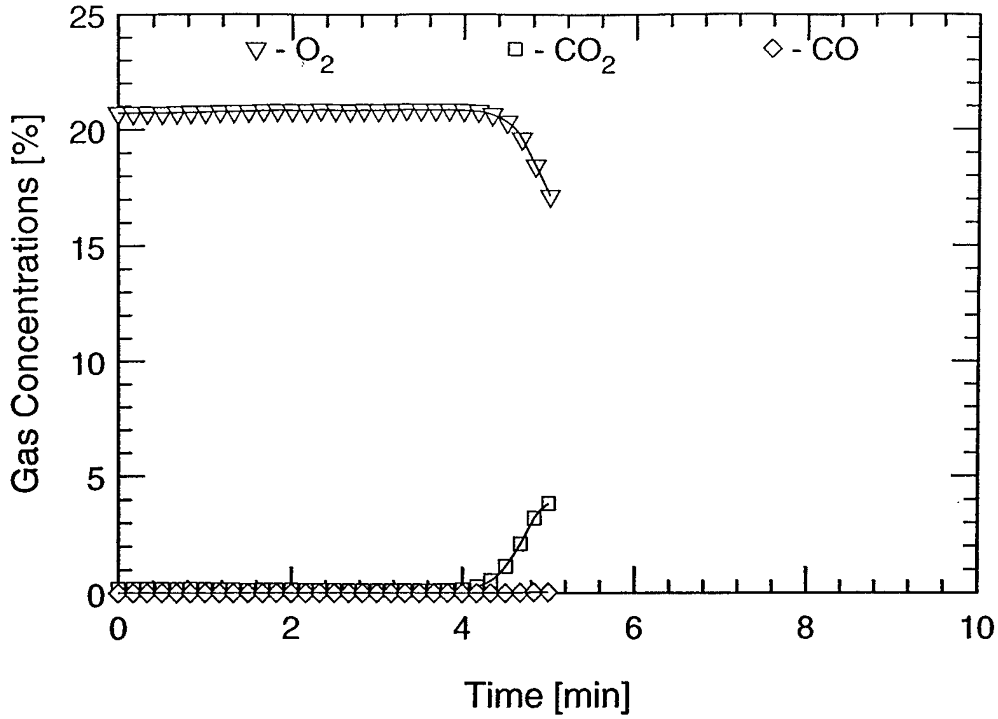


5-27-2

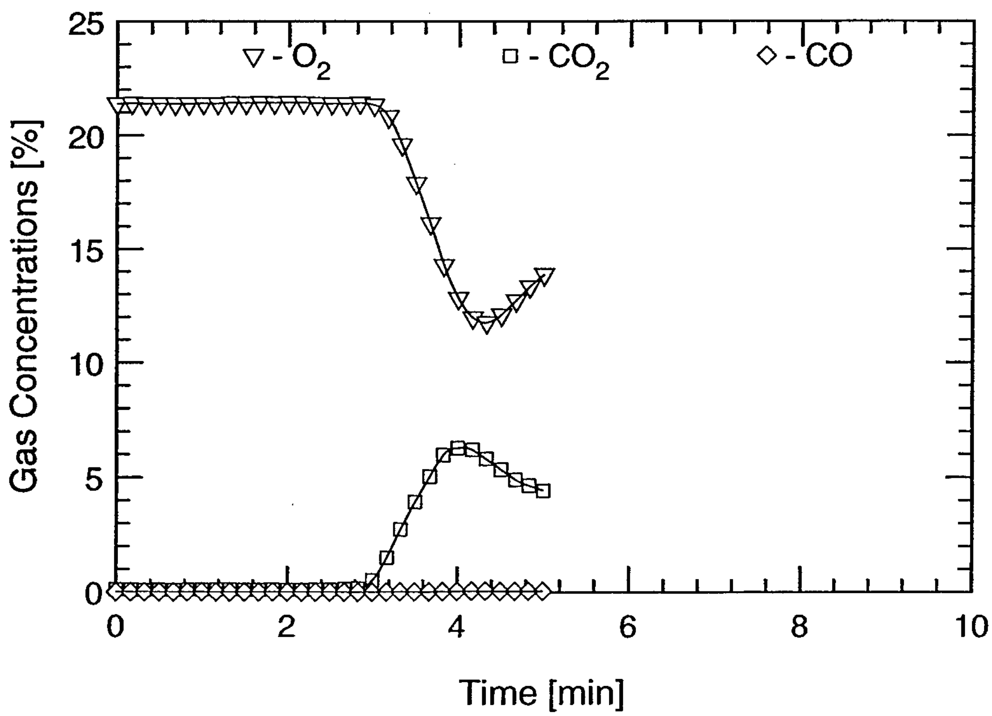


5-35-1

Test #25

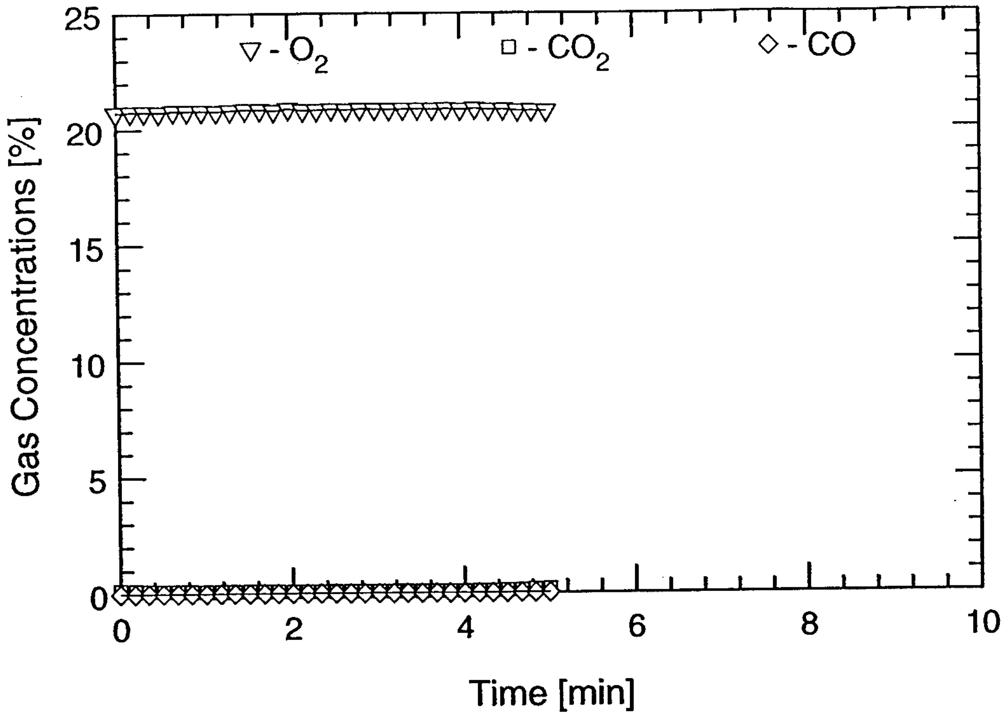


FR 22 - 0.5 m

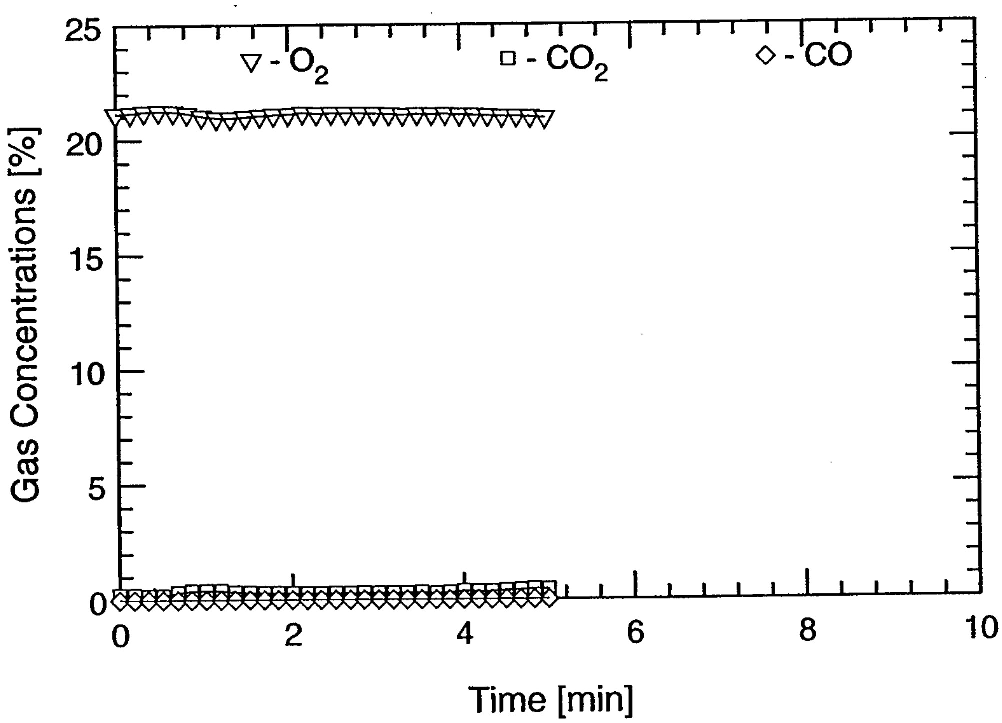


FR 22 - 4.5 m

Test #25

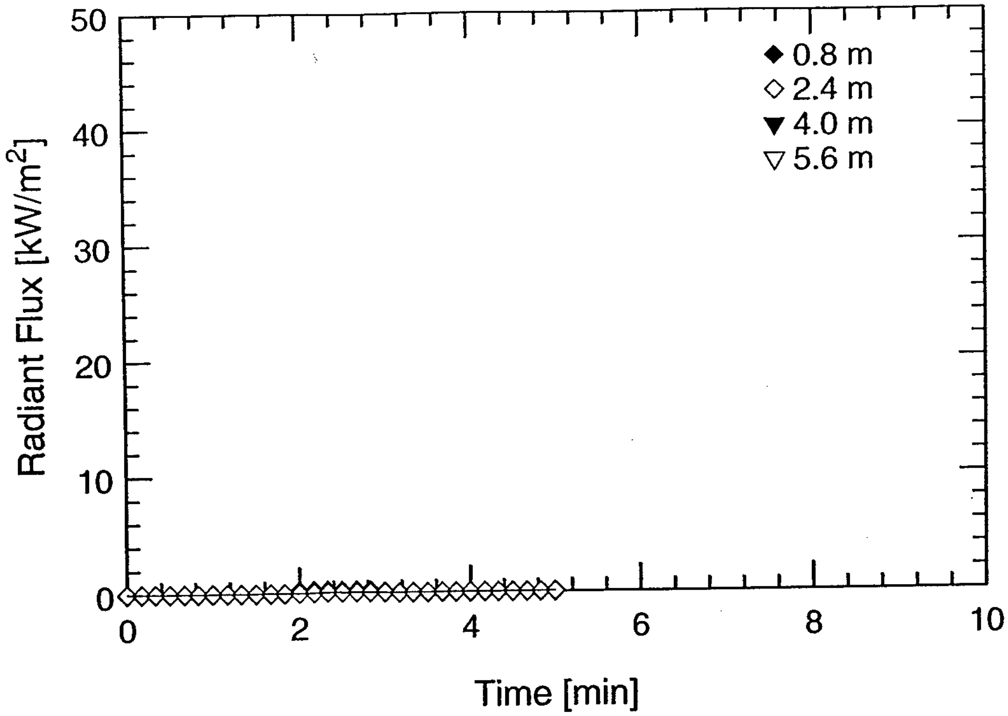


FR 36 - 0.5 m

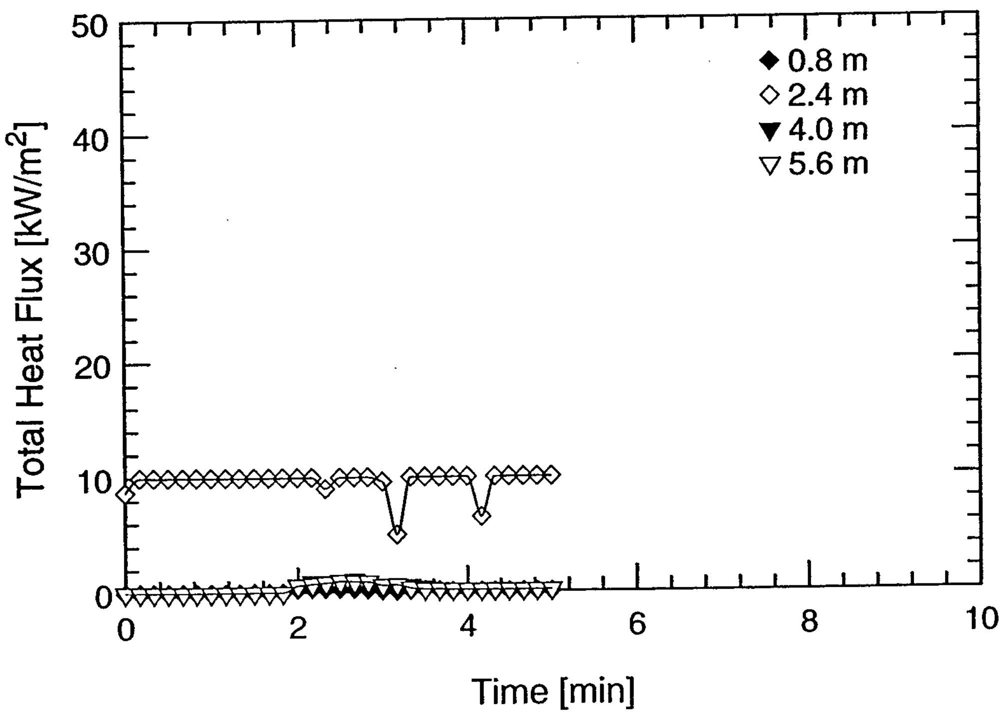


FR 36 - 4.5 m

Test #25

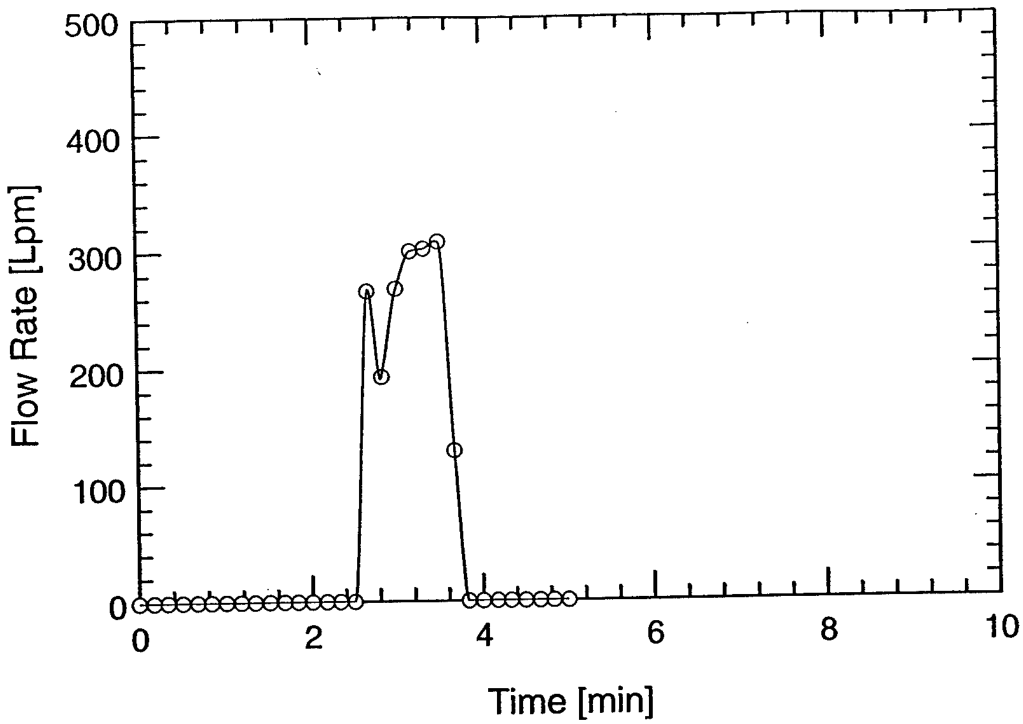


FR 22

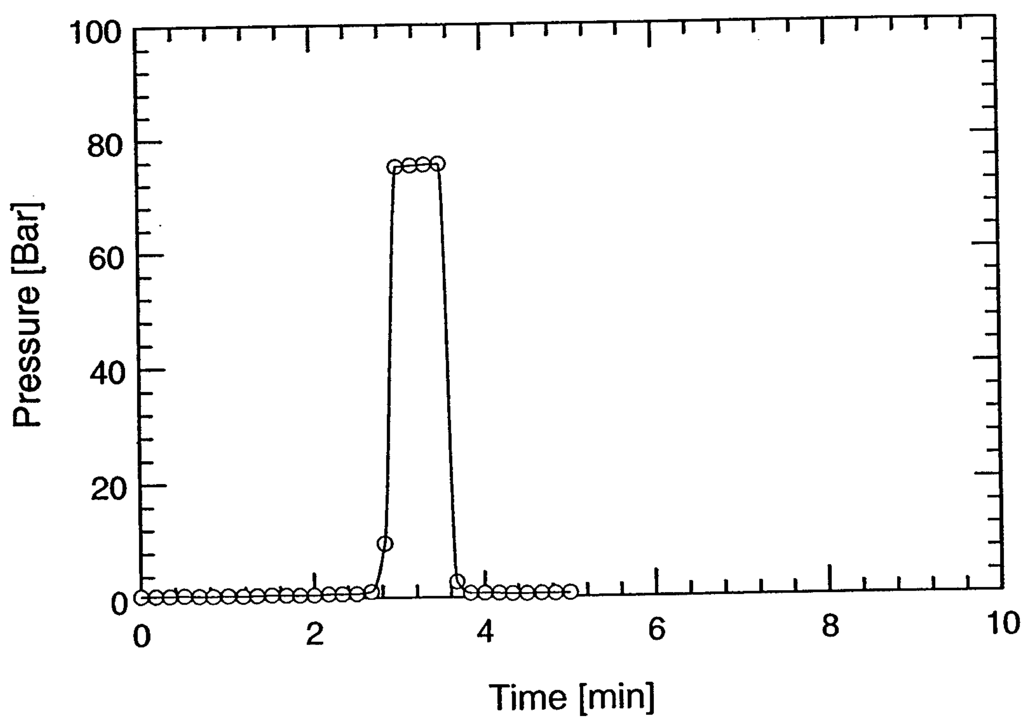


FR 22

Test #25

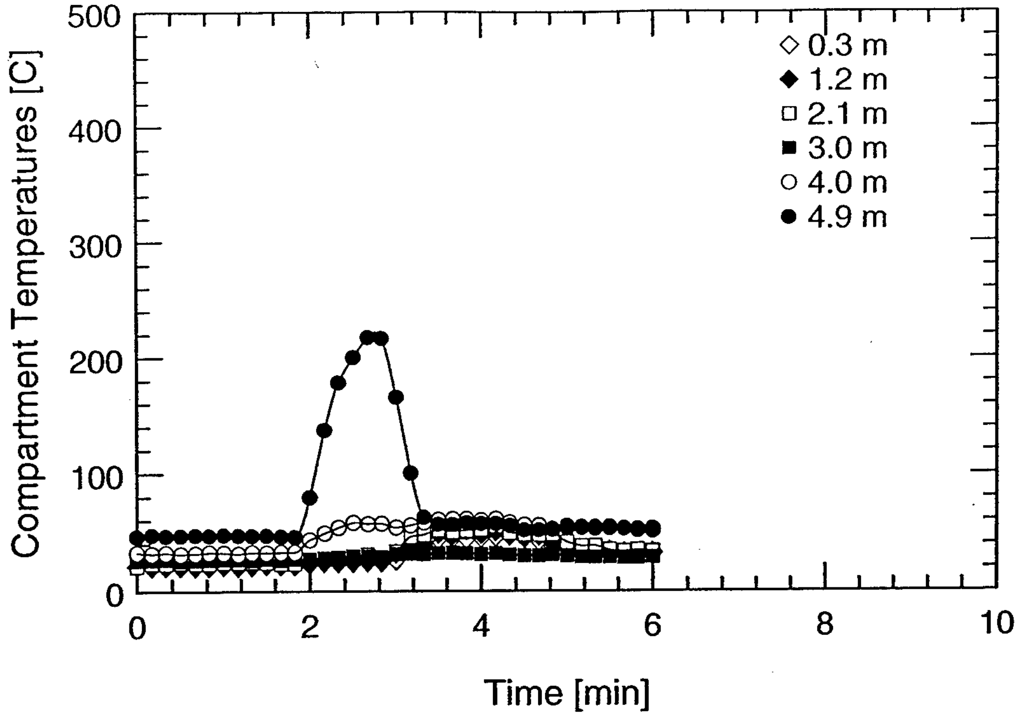


Water Mist System Flow Rate

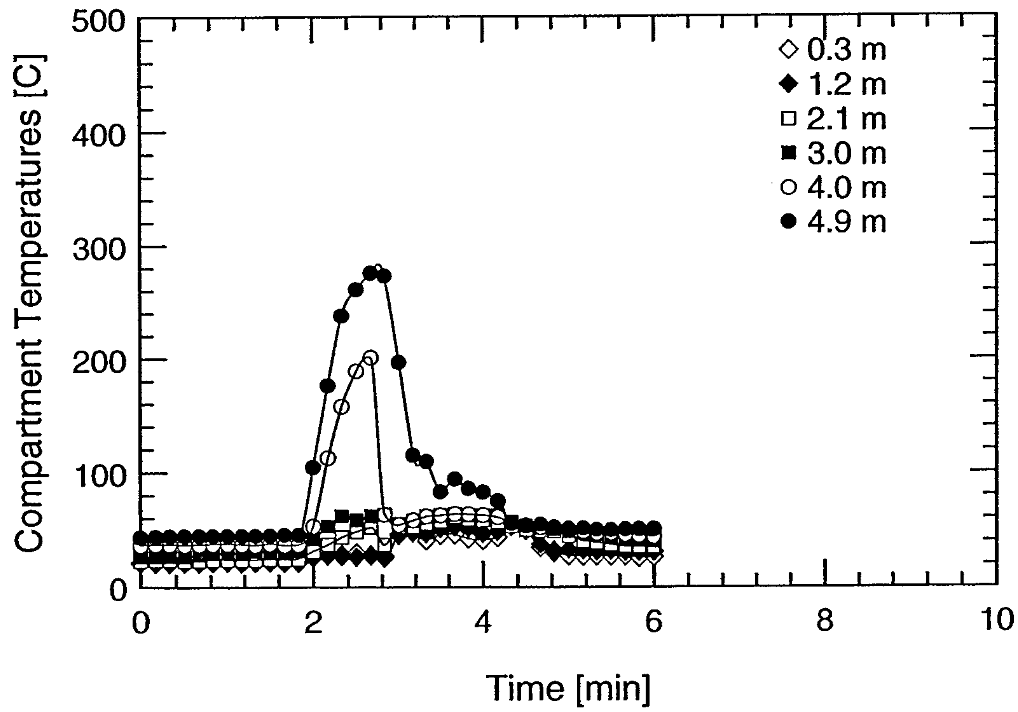


Water Mist System Pressure

Test #25

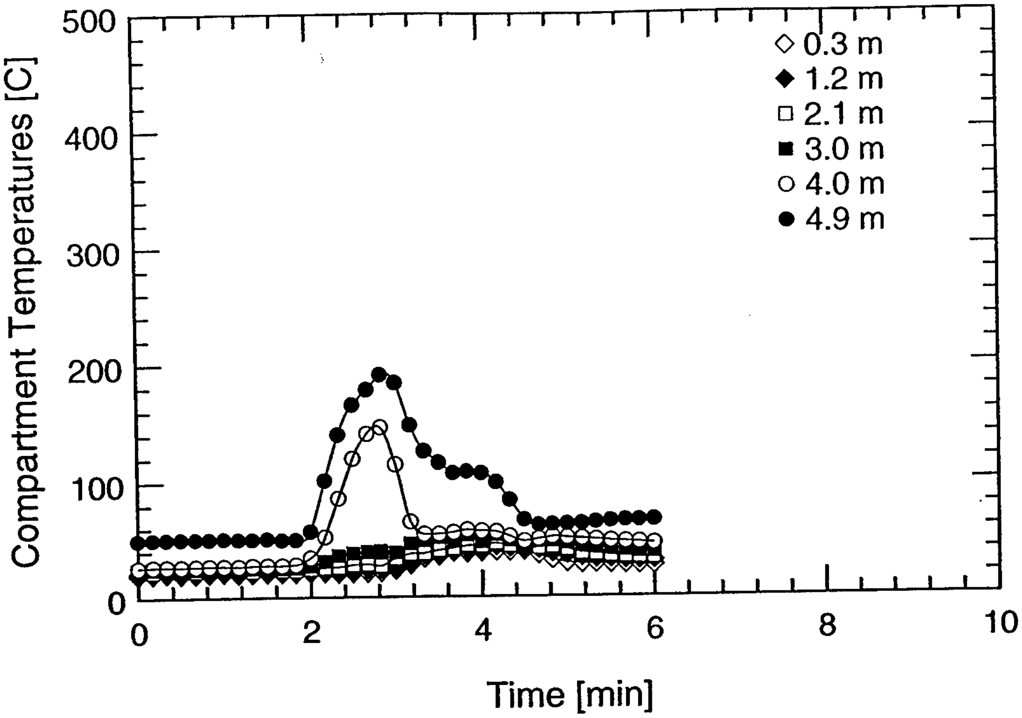


5-22-1

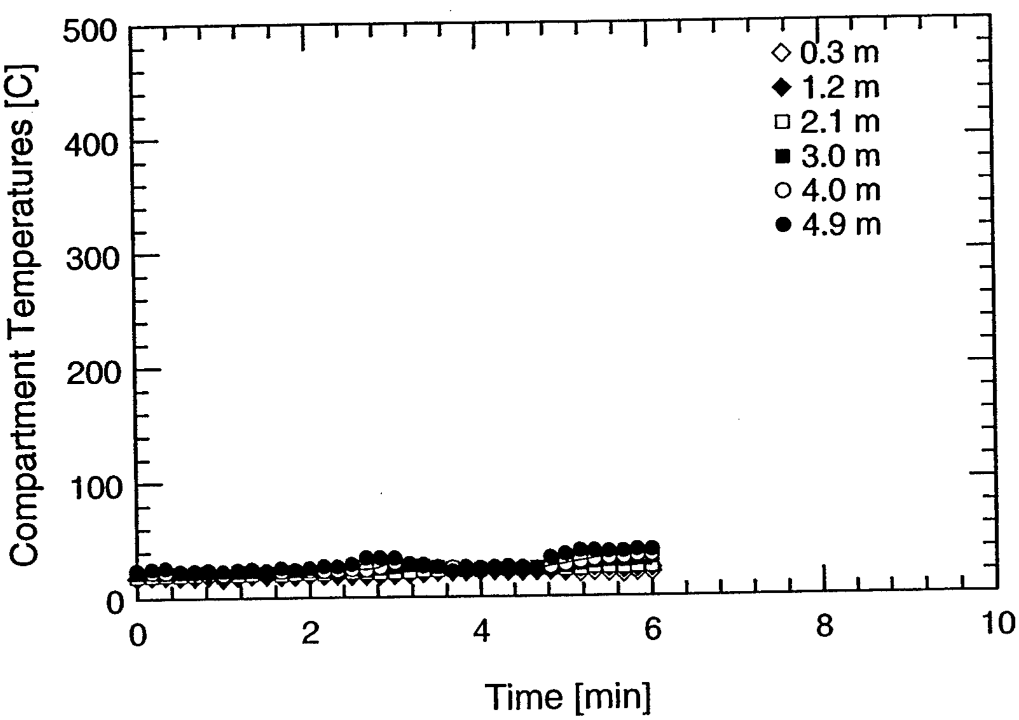


5-27-1

Test #26

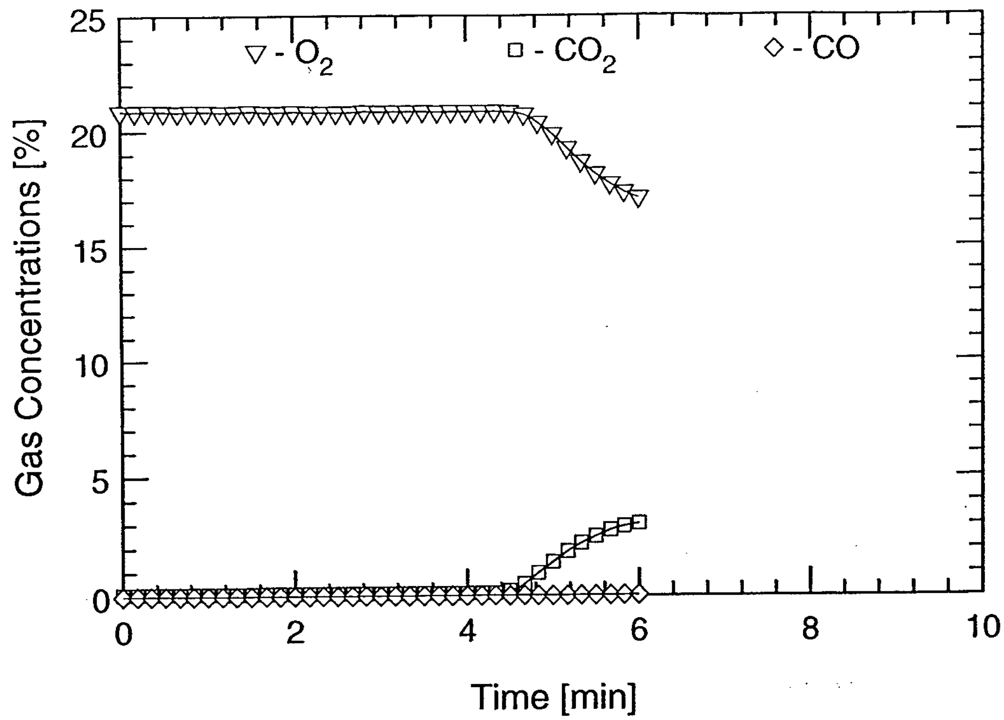


5-27-2

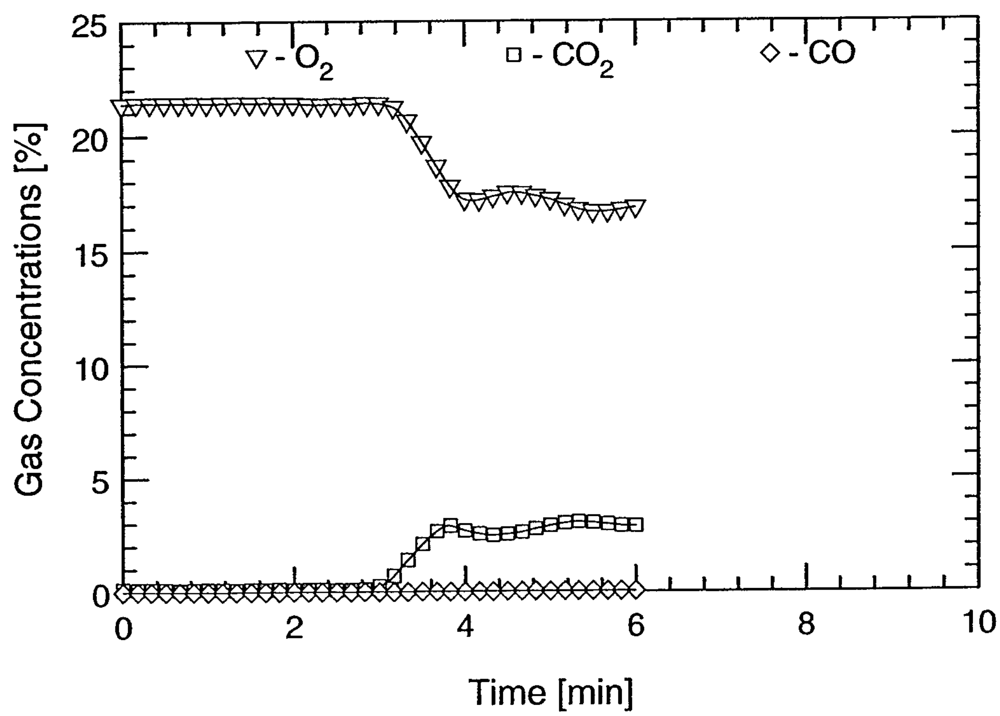


5-35-1

Test #26

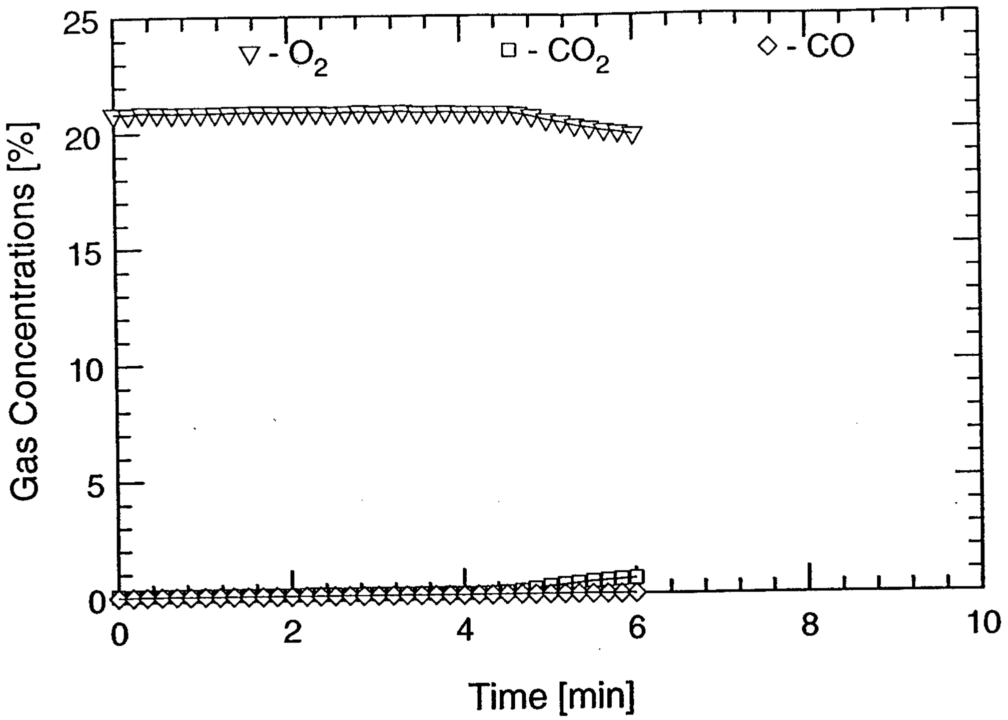


FR 22 - 0.5 m

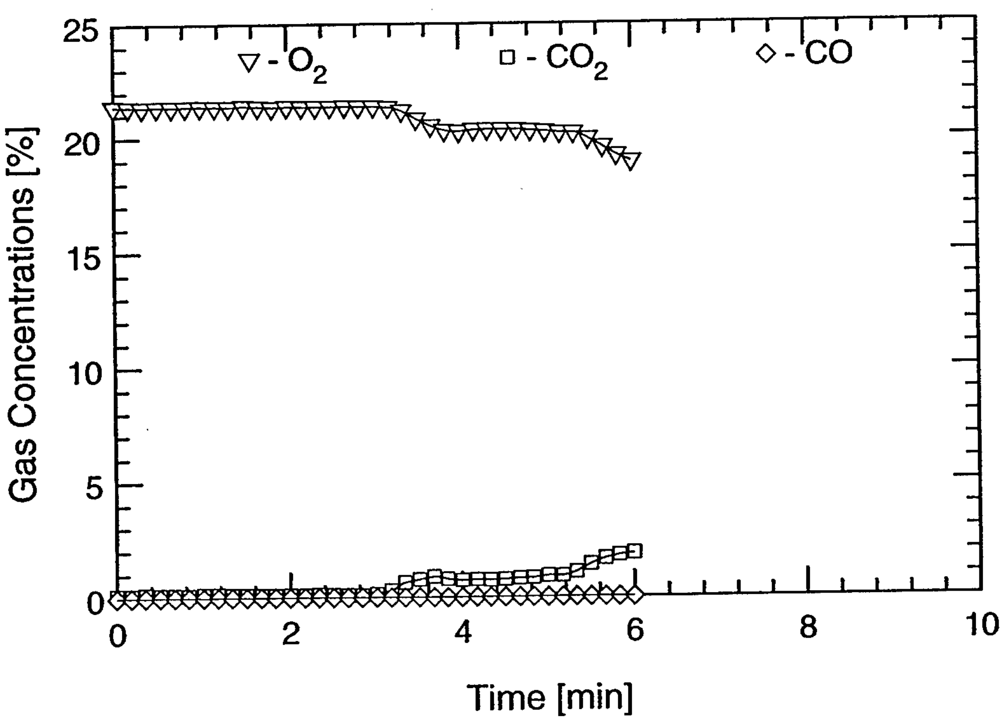


FR 22 - 4.5 m

Test #26

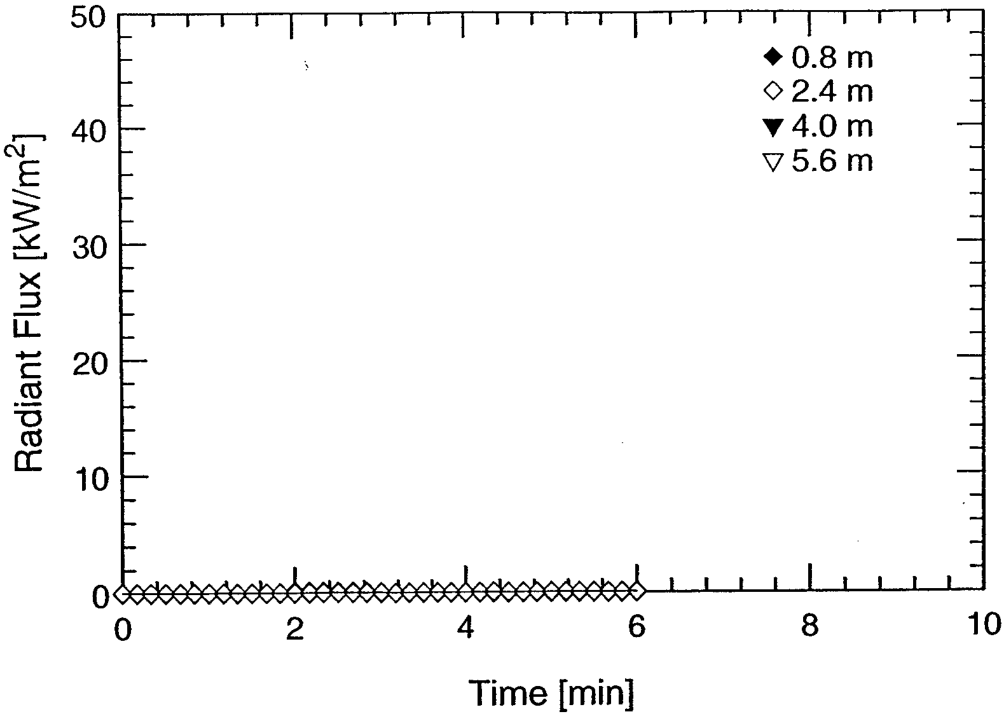


FR 36 - 0.5 m

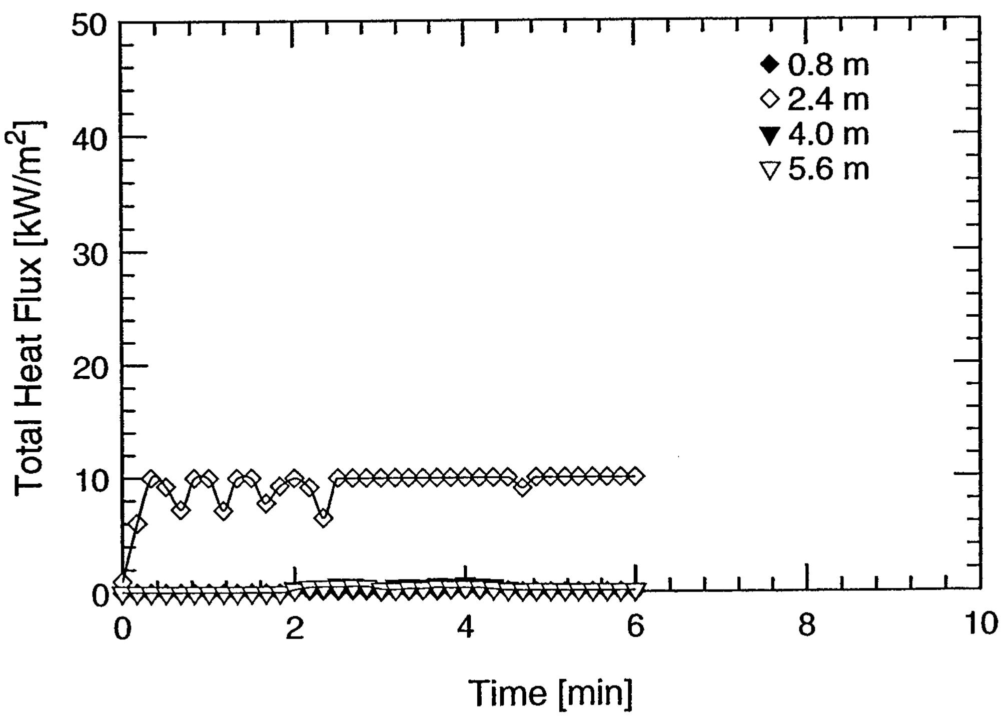


FR 36 - 4.5 m

Test #26

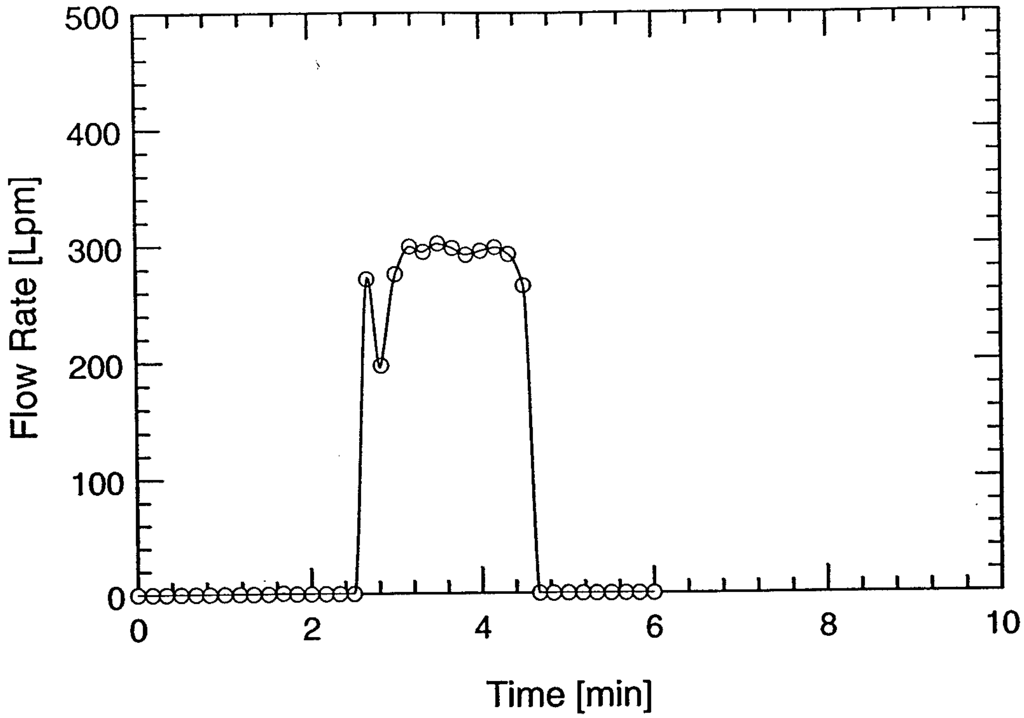


FR 22

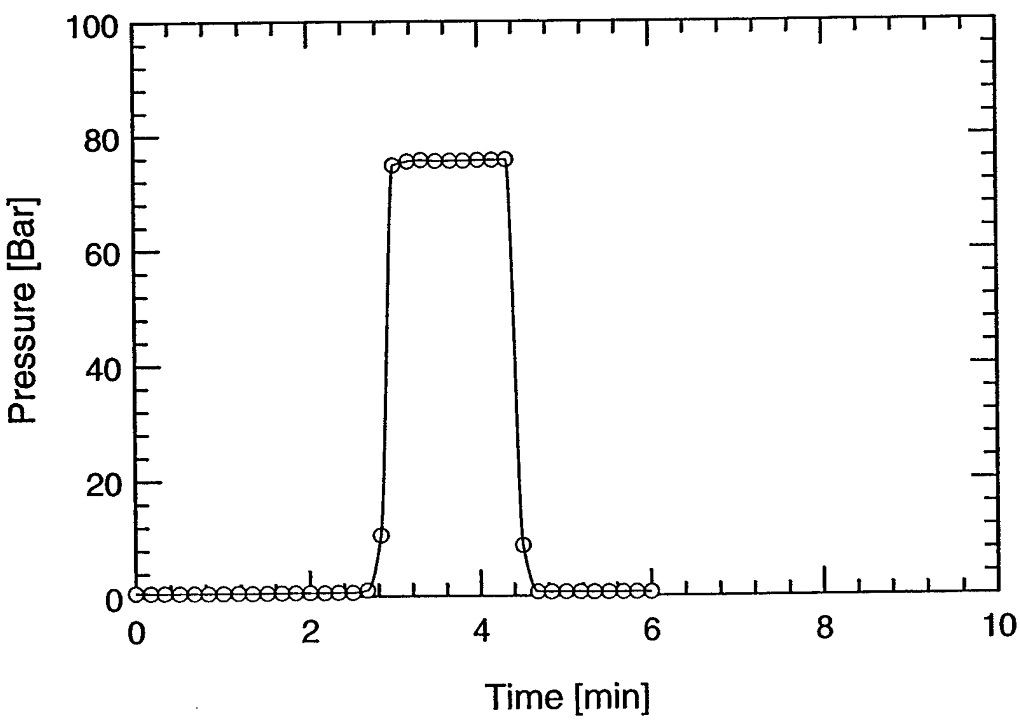


FR 22

Test #26

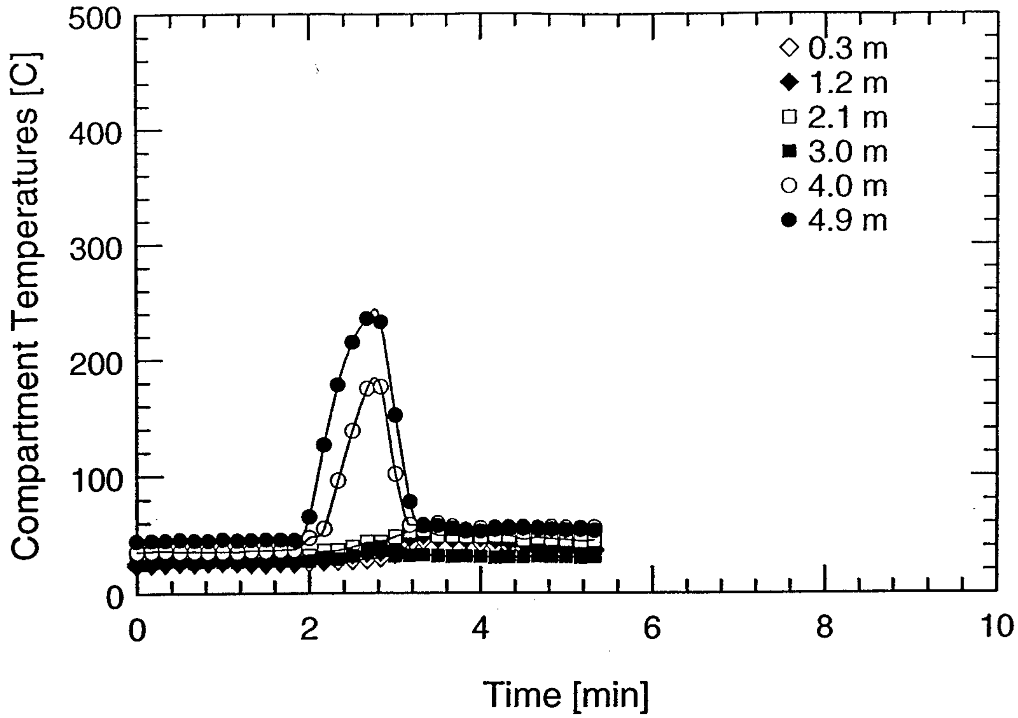


Water Mist System Flow Rate

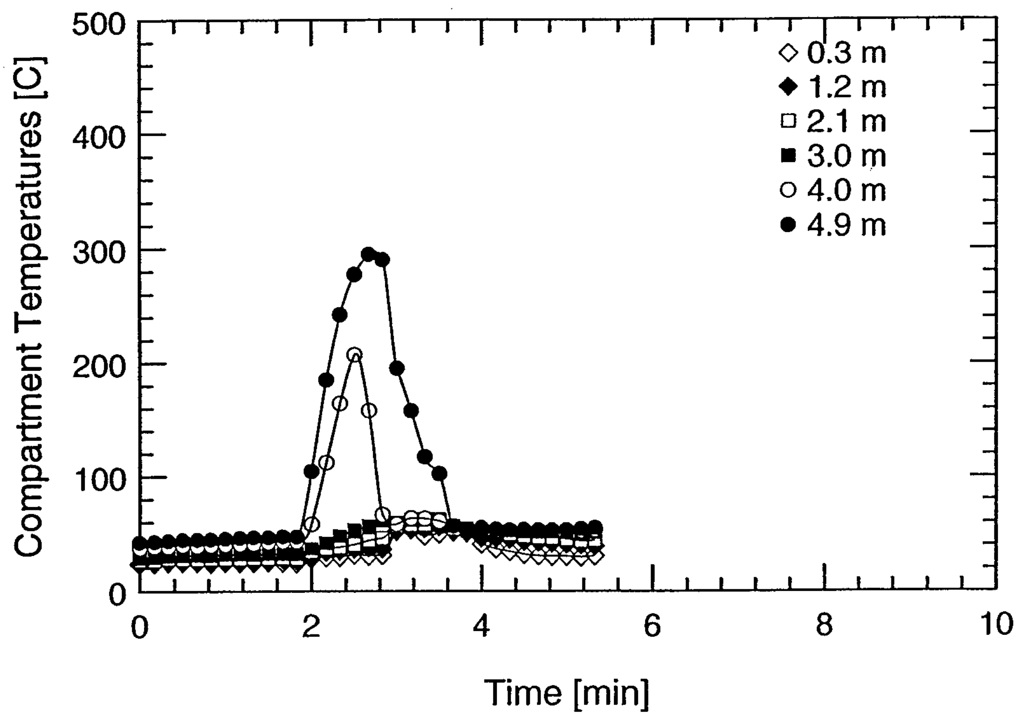


Water Mist System Pressure

Test #26

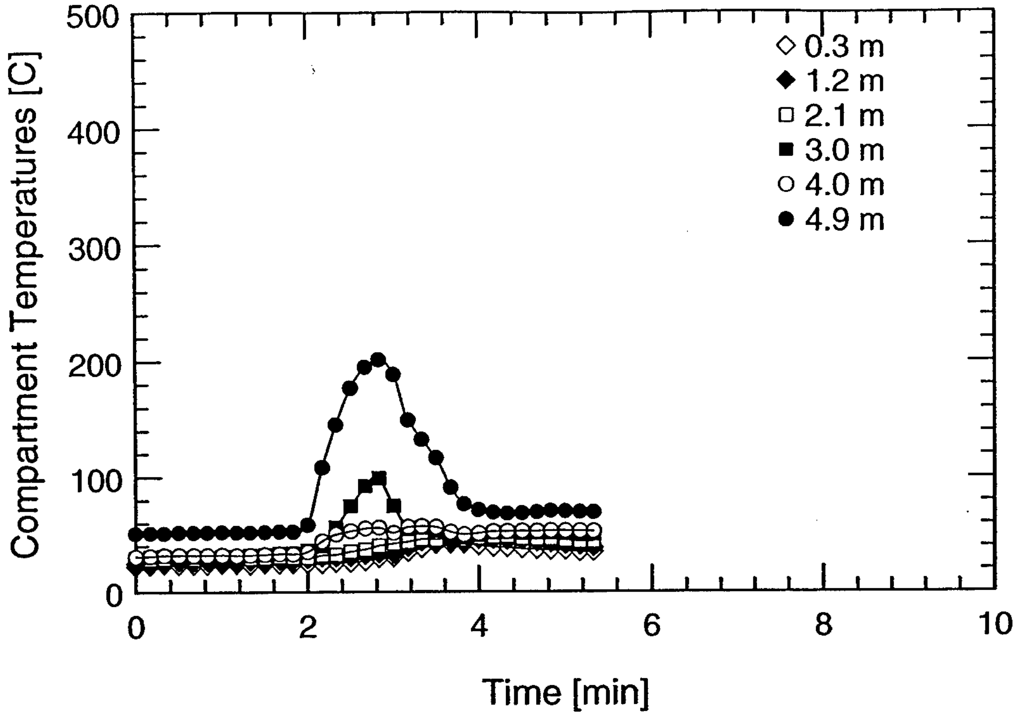


5-22-1

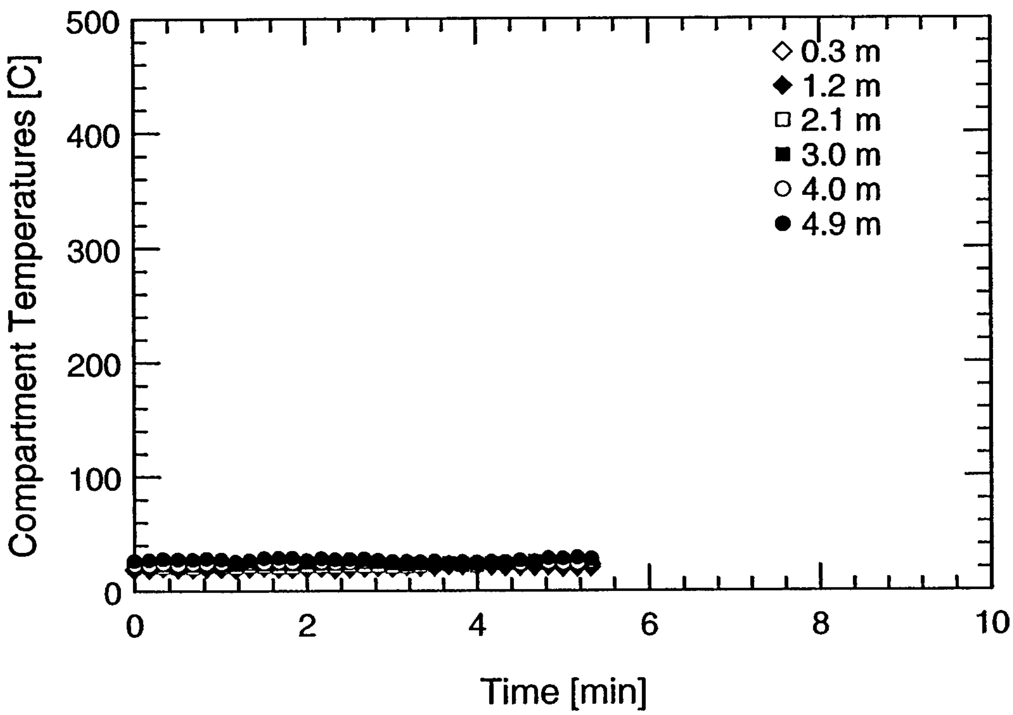


5-27-1

Test #27

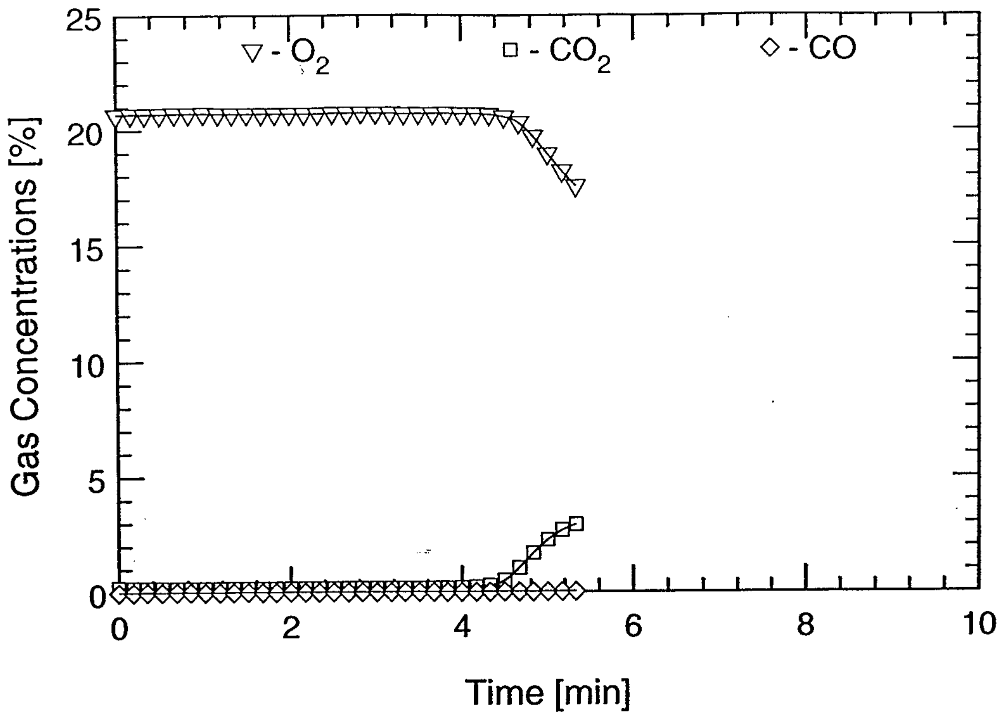


5-27-2

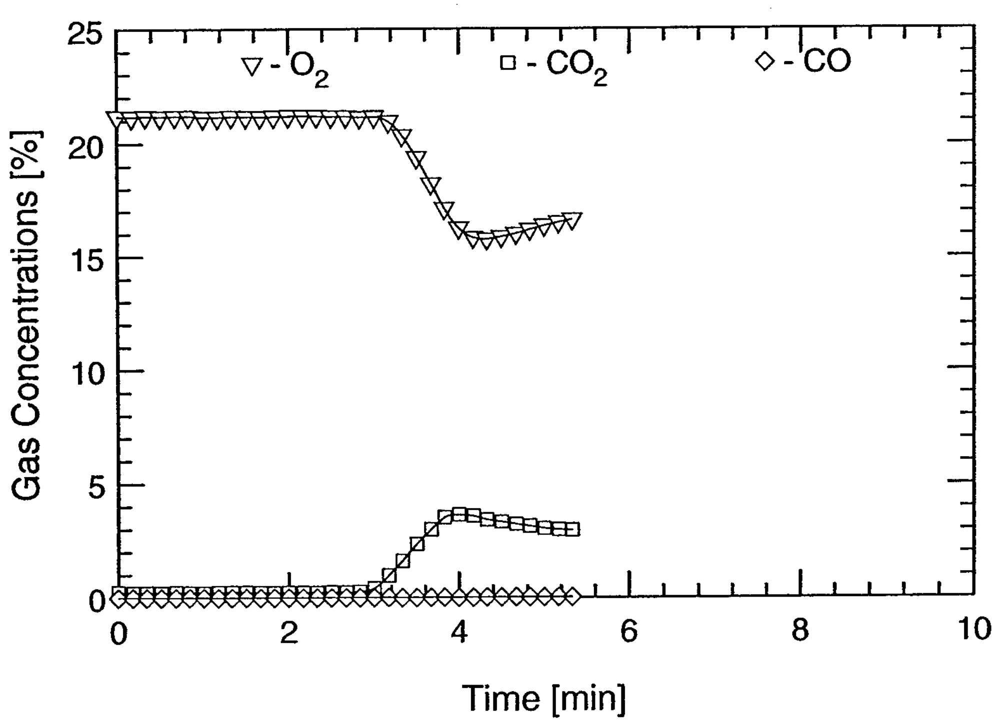


5-35-1

Test #27

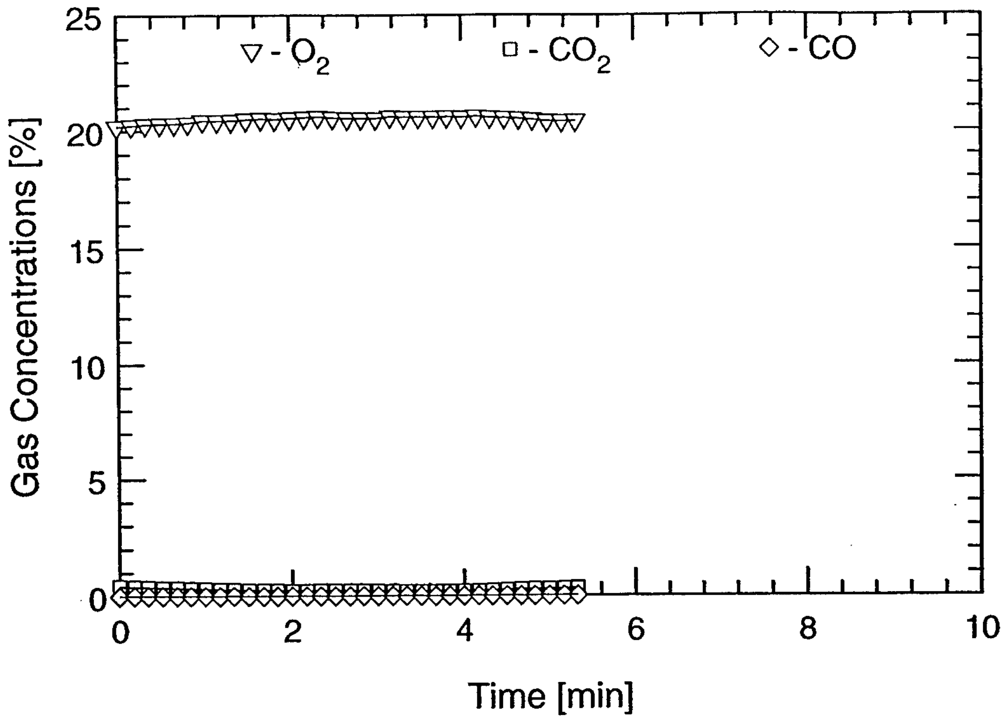


FR 22 - 0.5 m

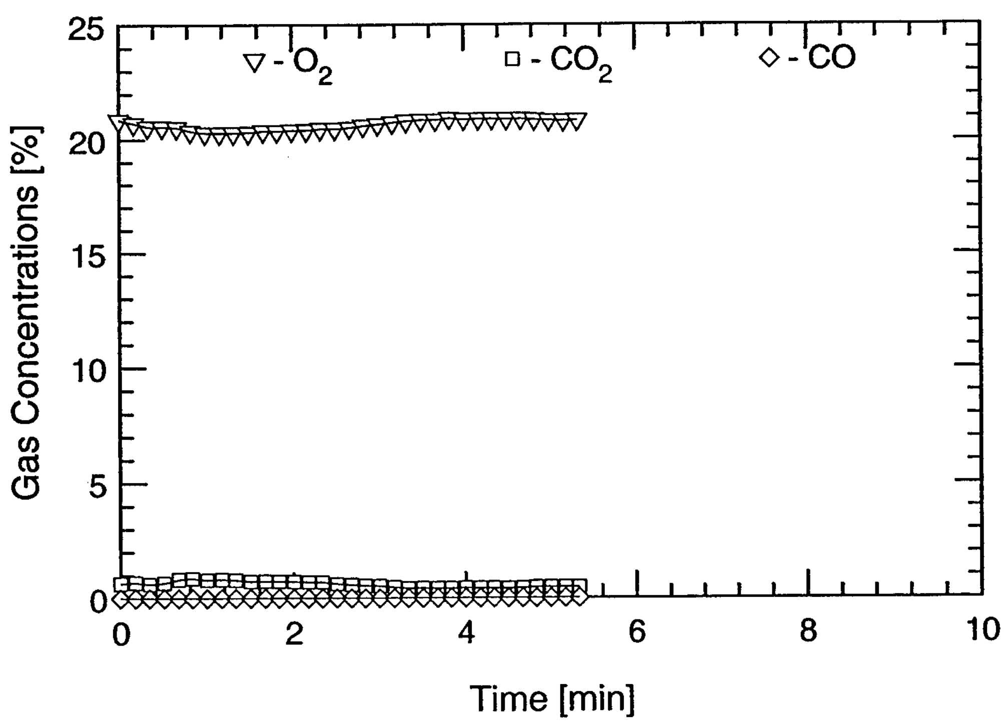


FR 22 - 4.5 m

Test #27

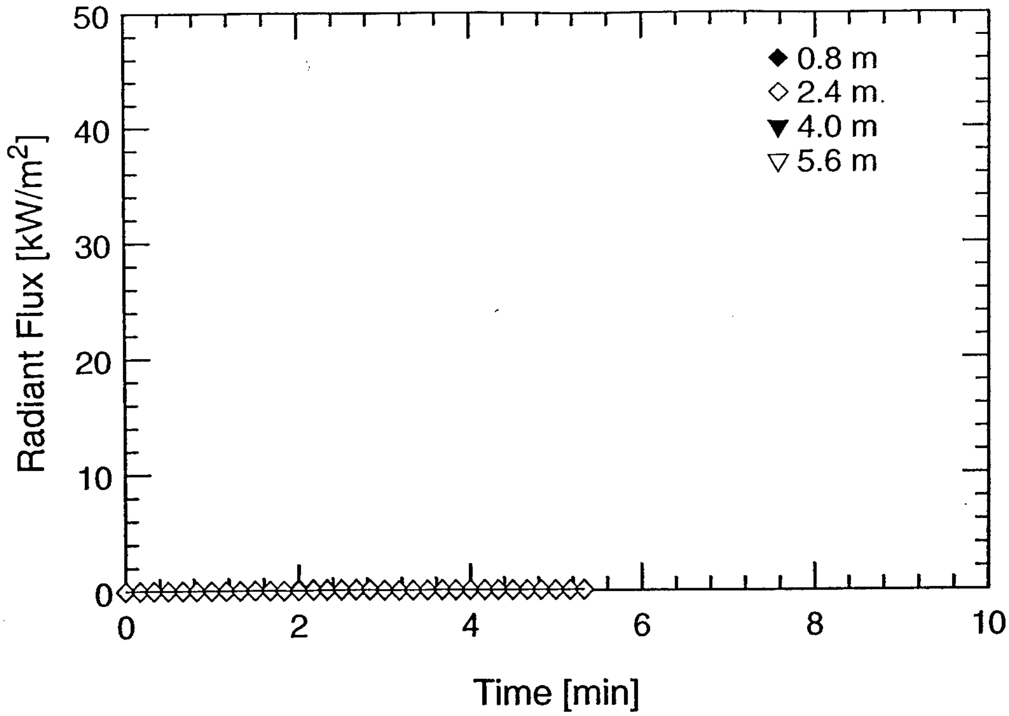


FR 36 - 0.5 m

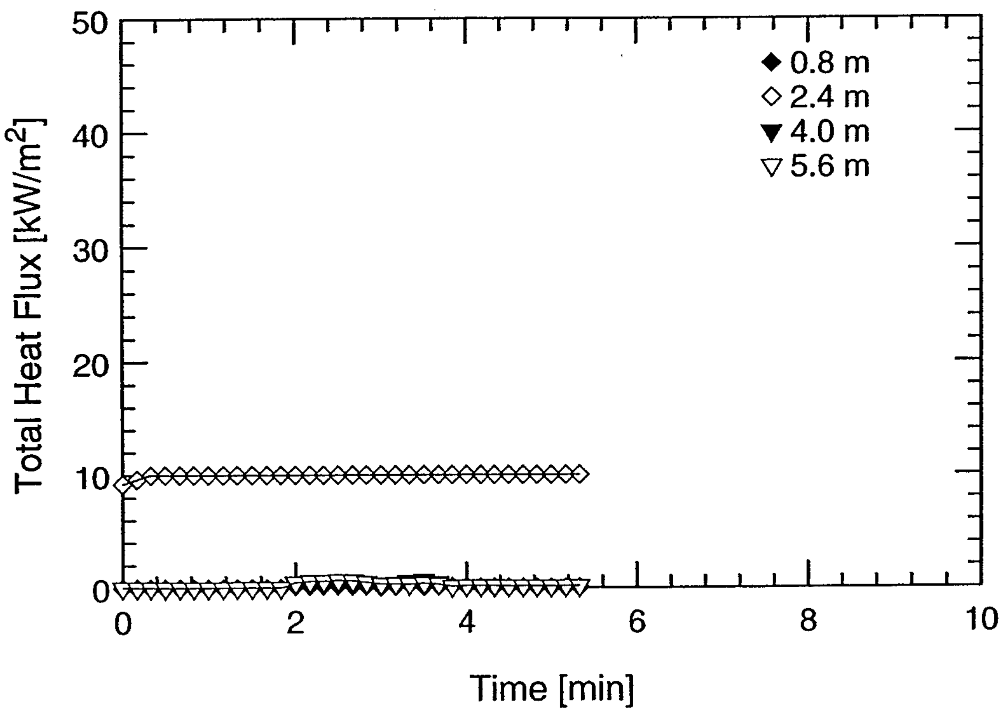


FR 36 - 4.5 m

Test #27

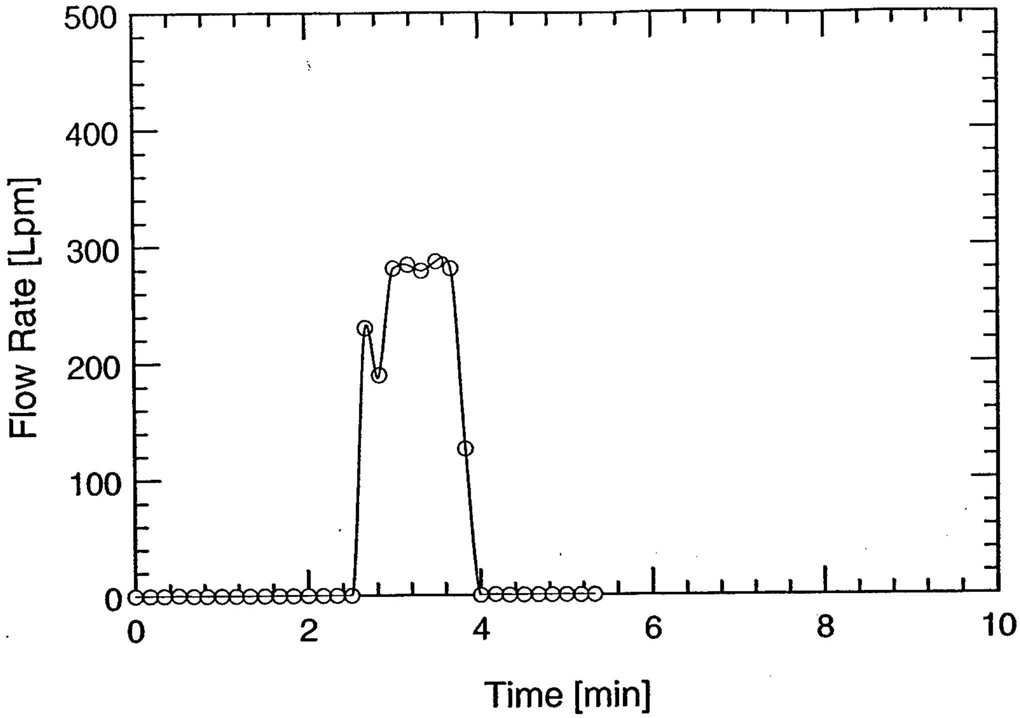


FR 22

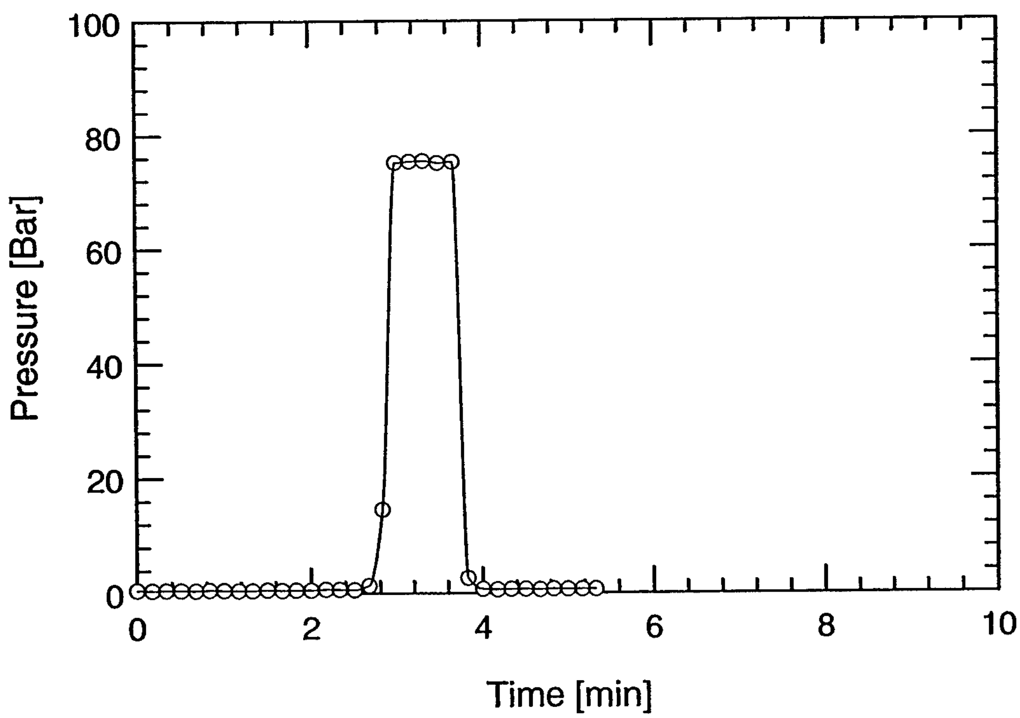


FR 22

Test #27

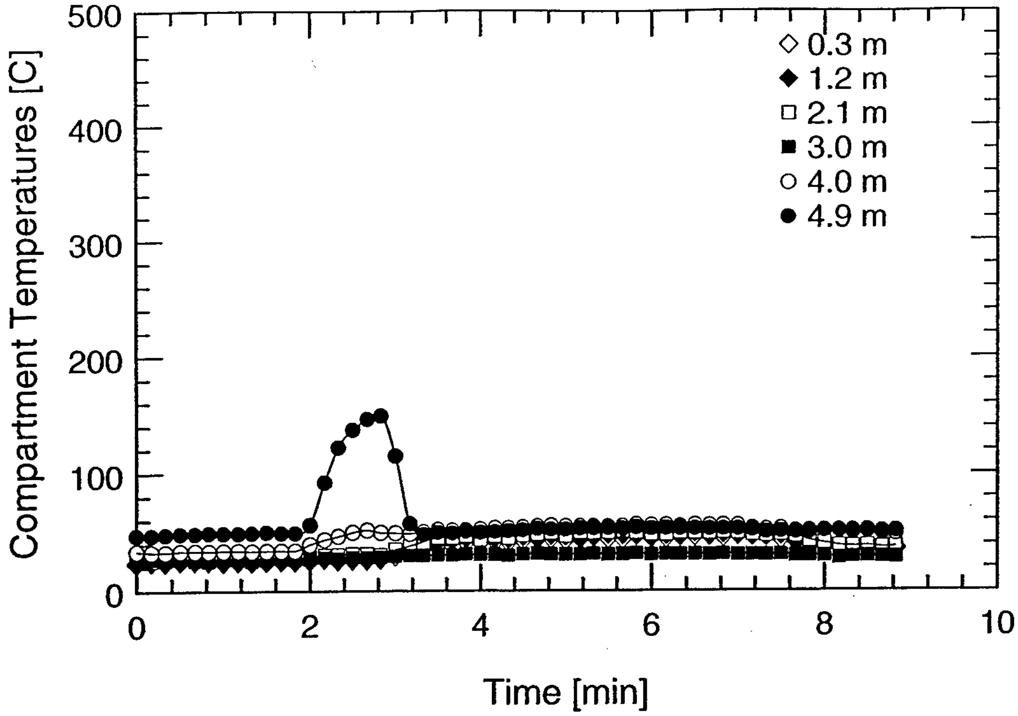


Water Mist System Flow Rate

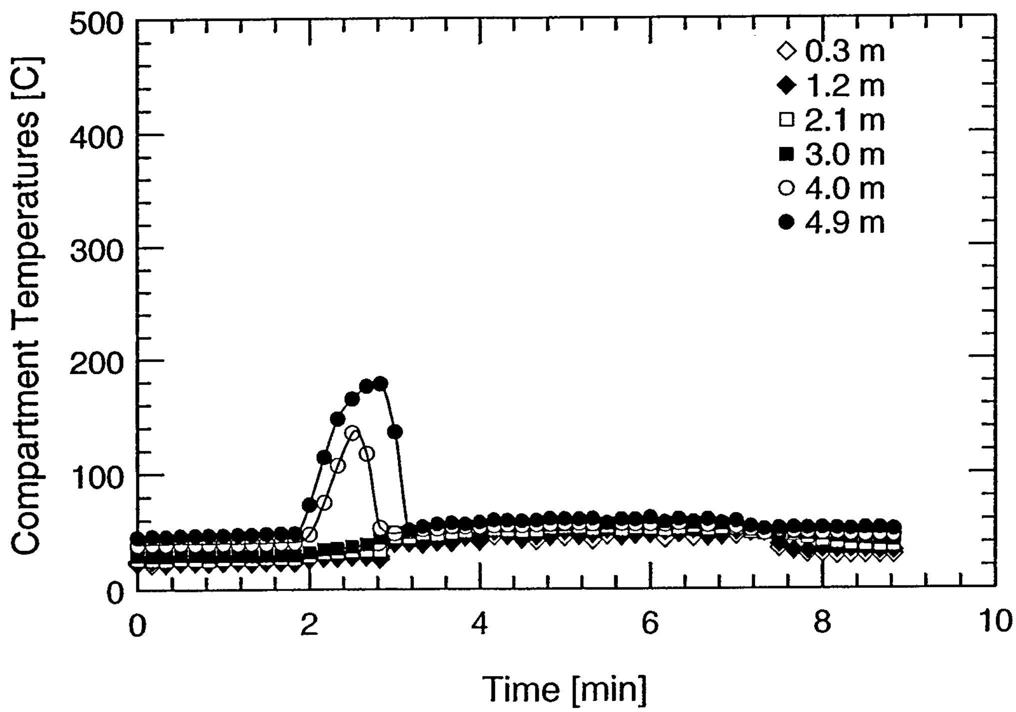


Water Mist System Pressure

Test #27

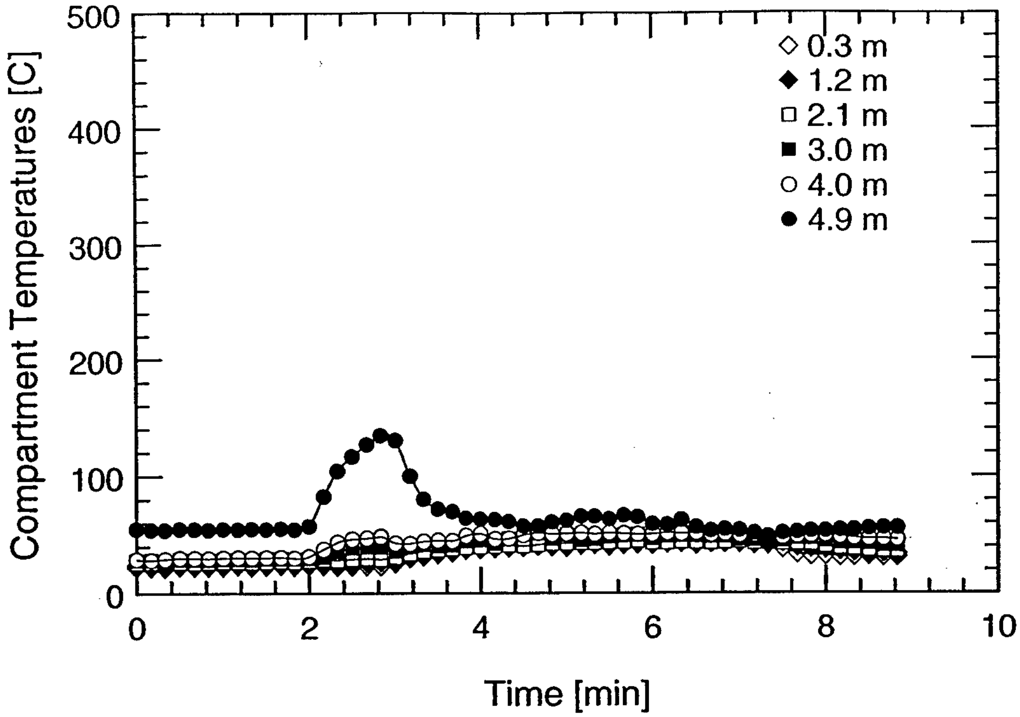


5-22-1

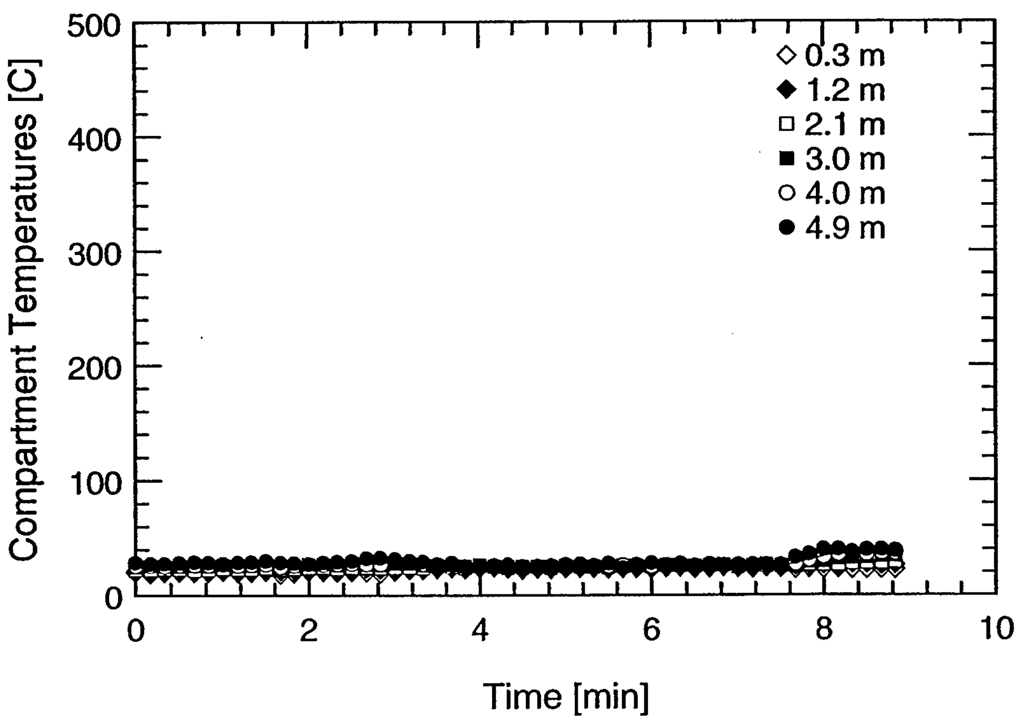


5-27-1

Test #28

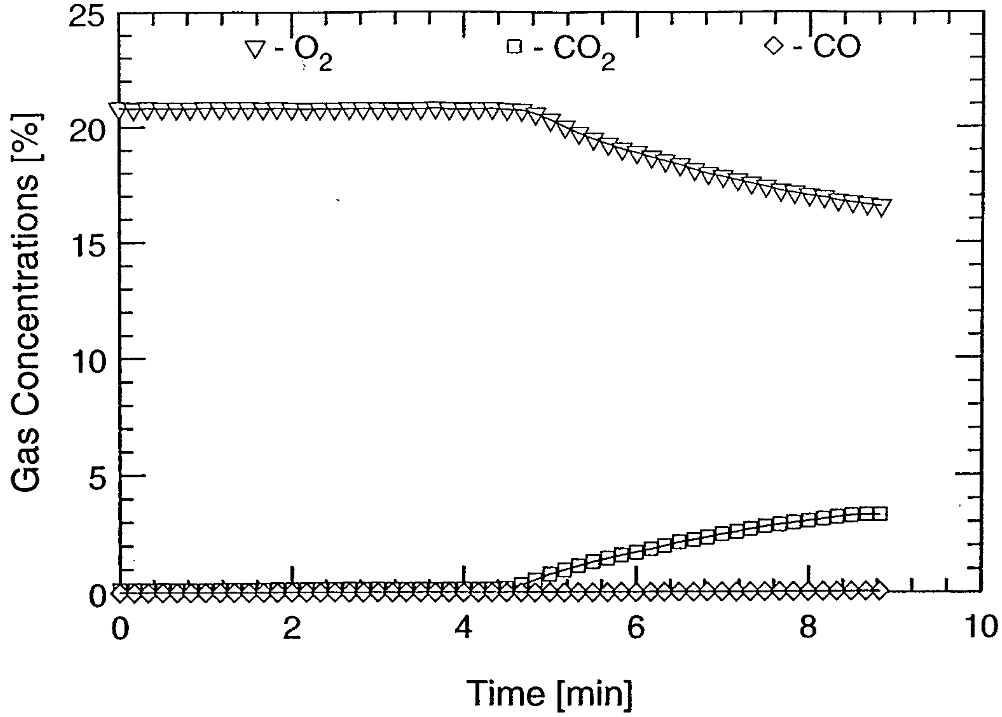


5-27-2

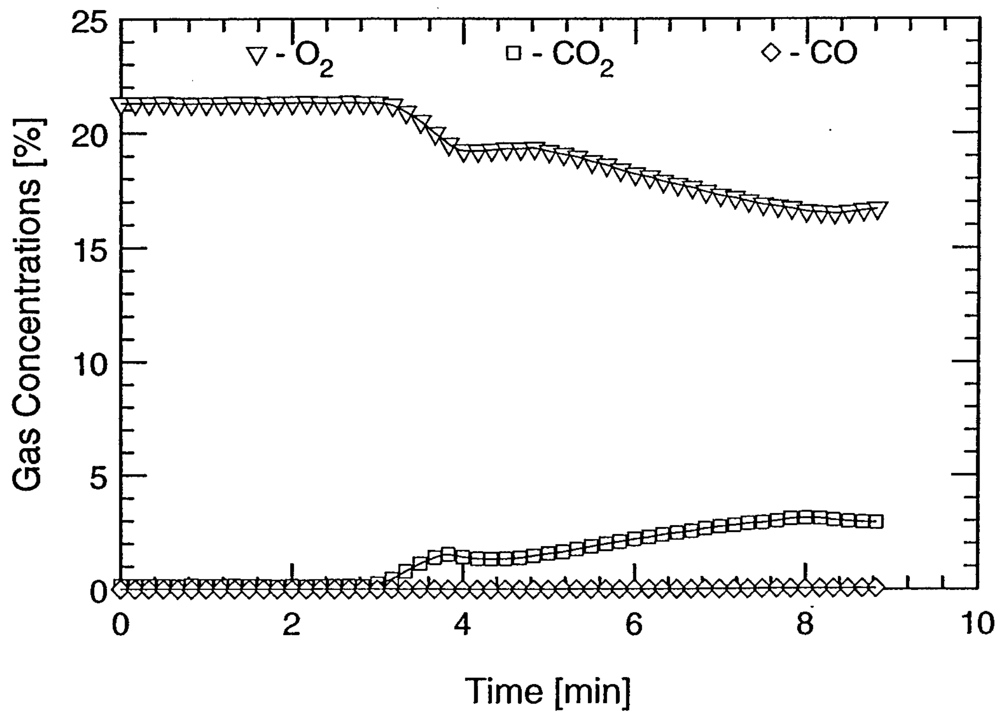


5-35-1

Test #28

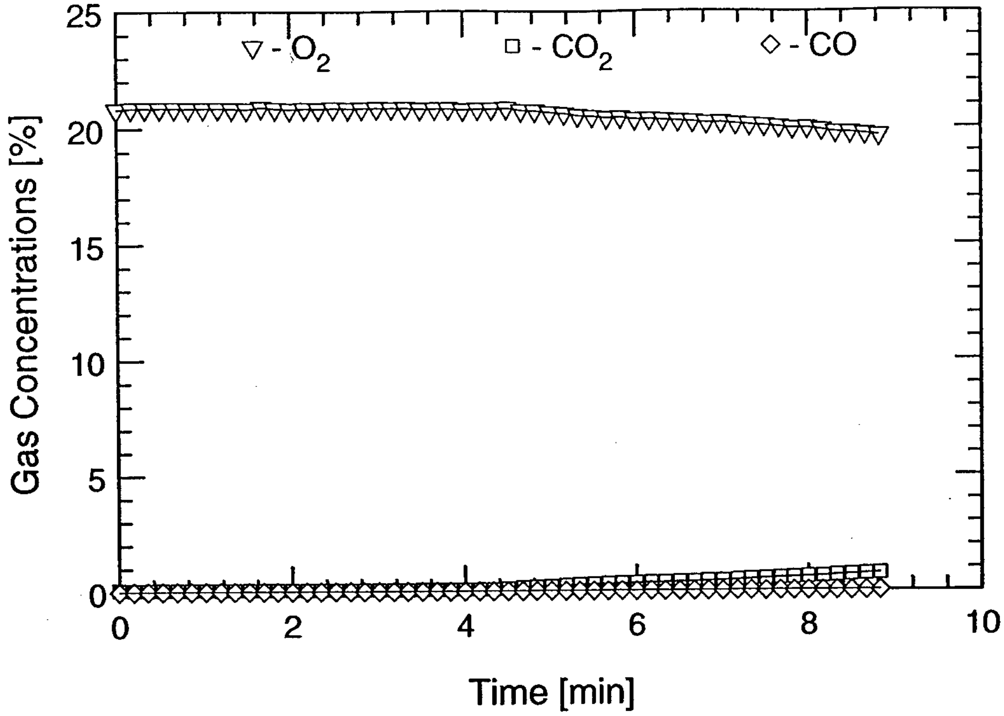


FR 22 - 0.5 m

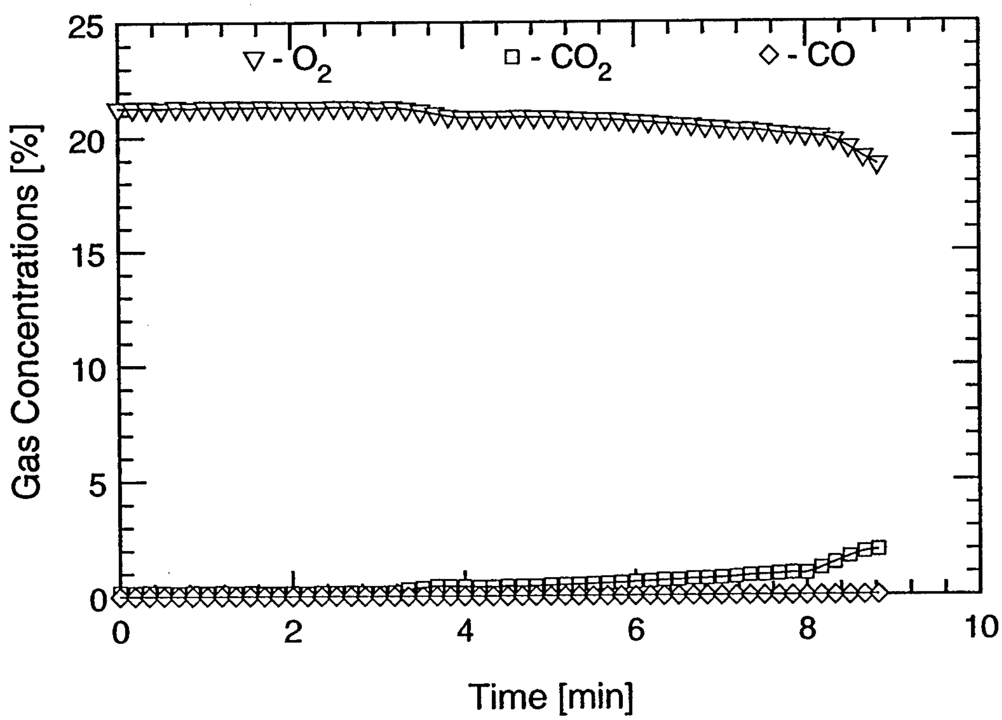


FR 22 - 4.5 m

Test #28

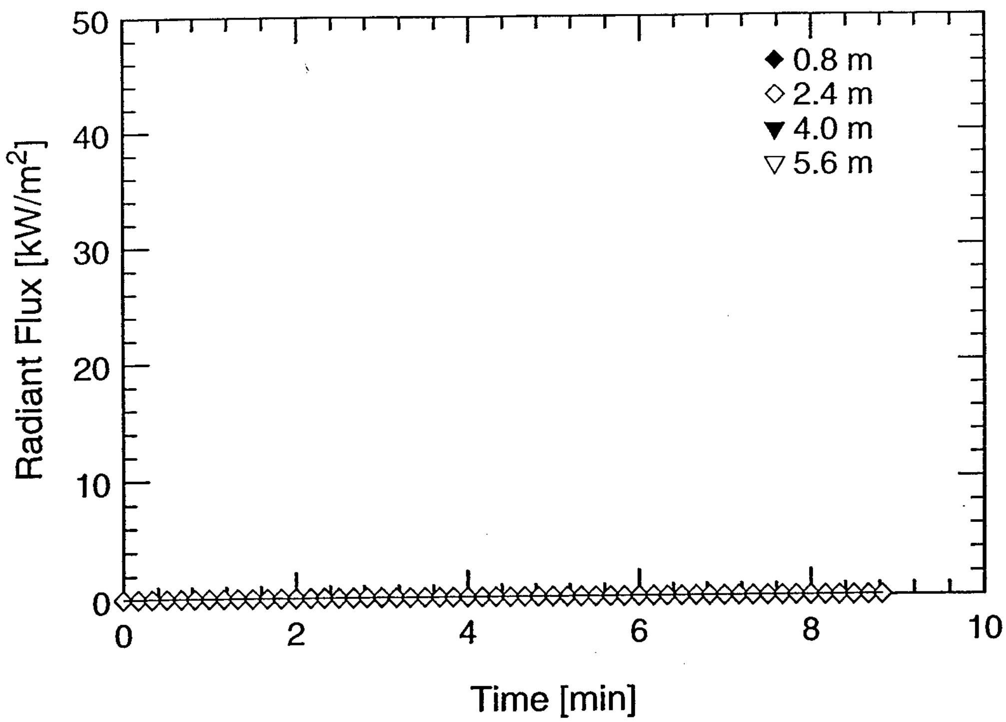


FR 36 - 0.5 m

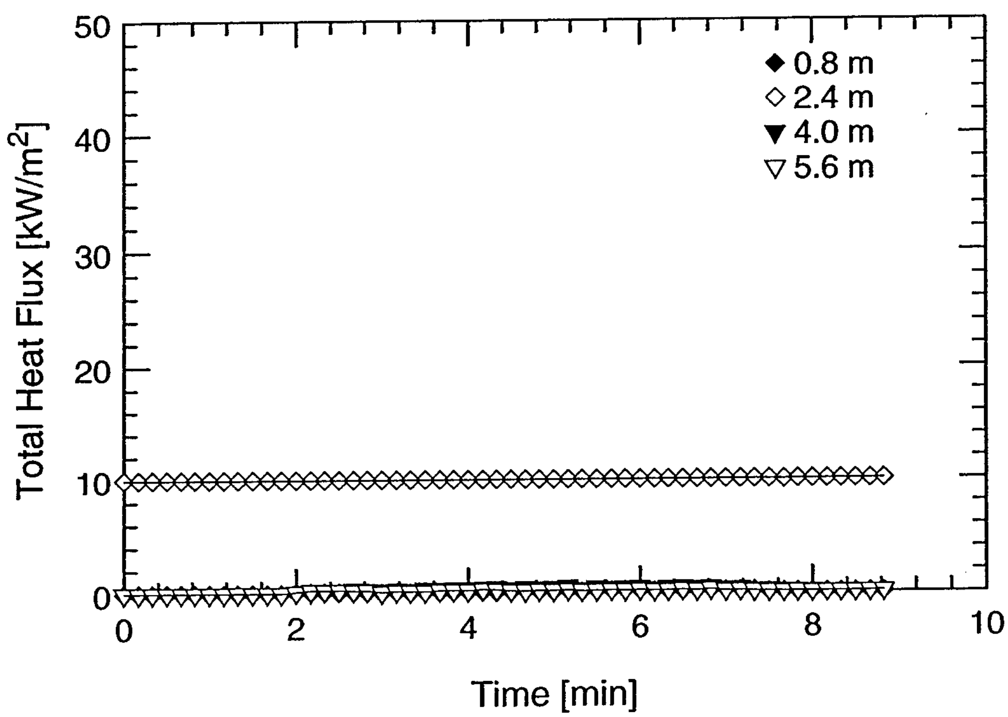


FR 36 - 4.5 m

Test #28

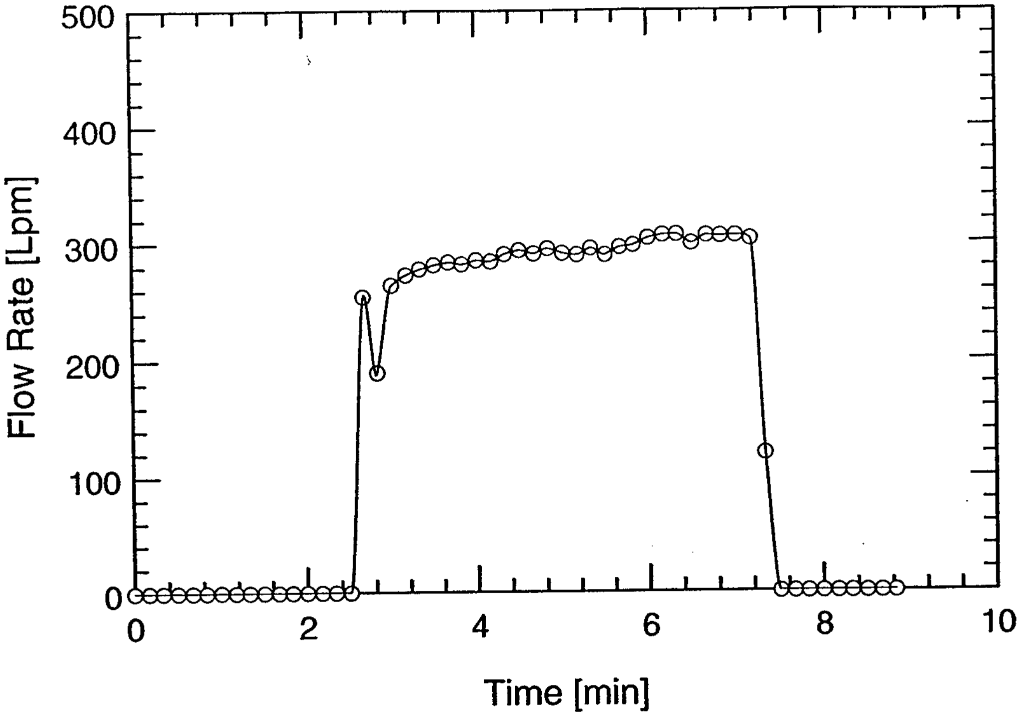


FR 22

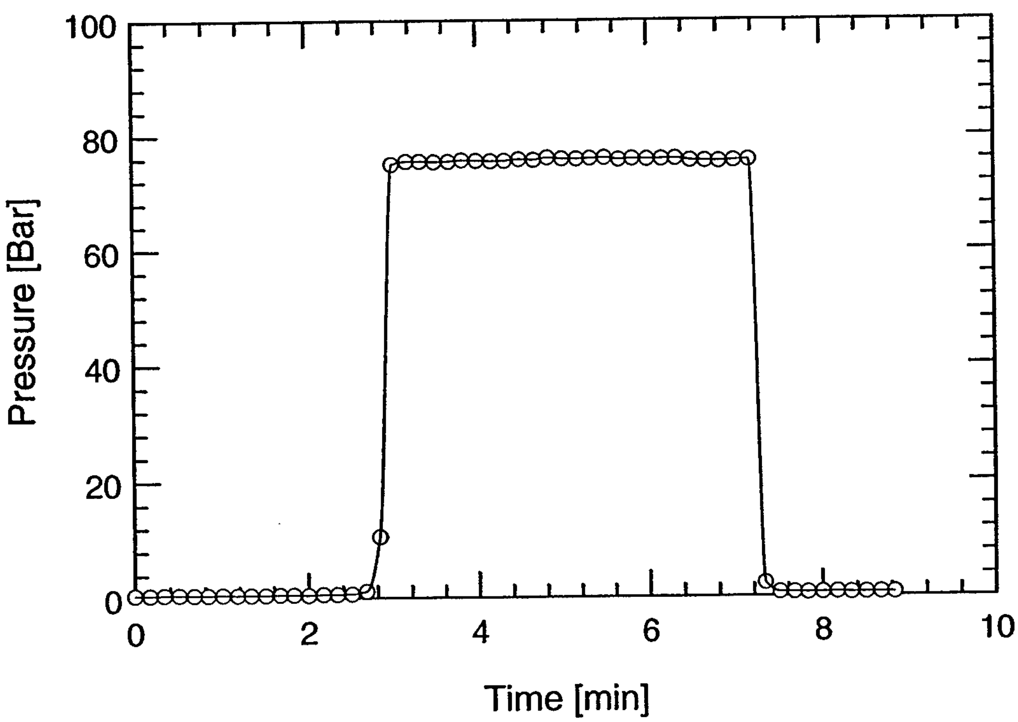


FR 22

Test #28

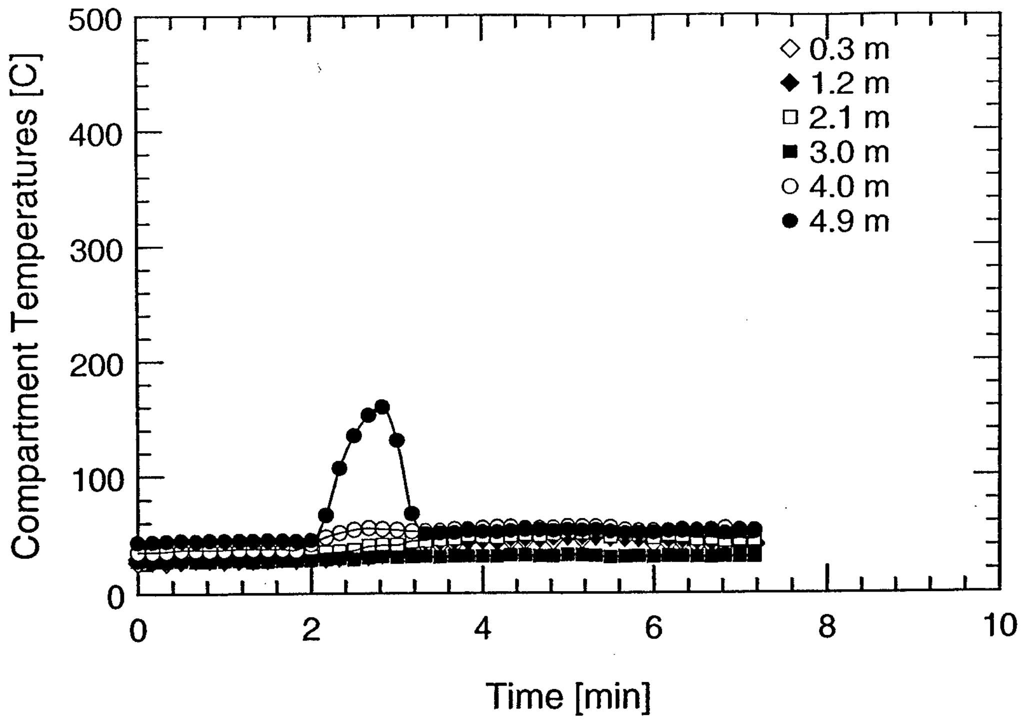


Water Mist System Flow Rate

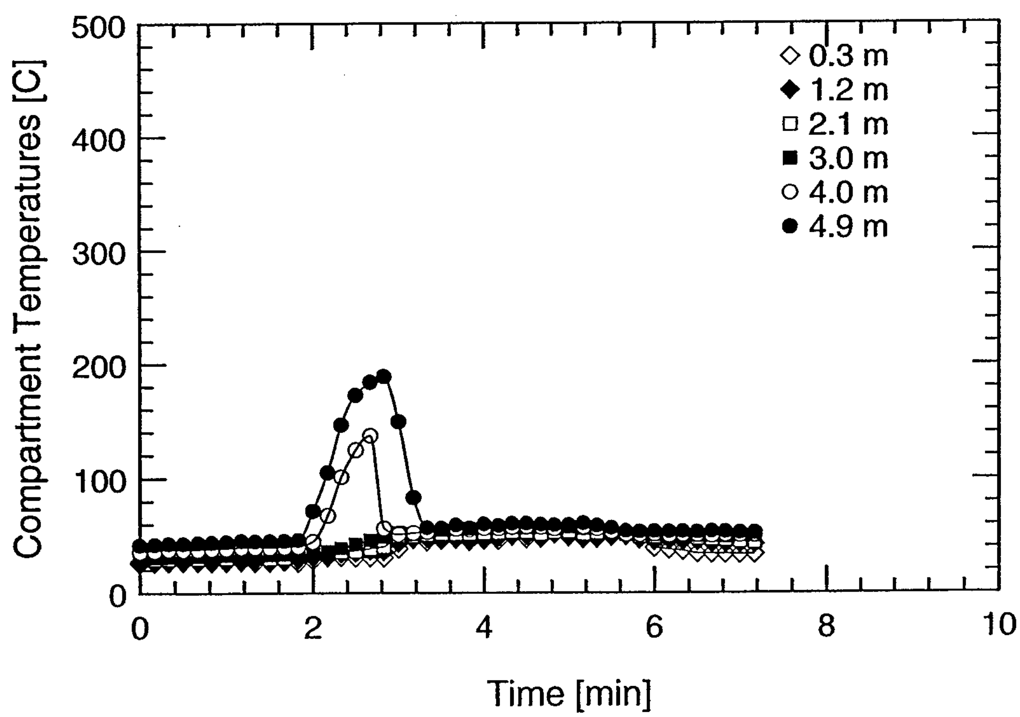


Water Mist System Pressure

Test #28

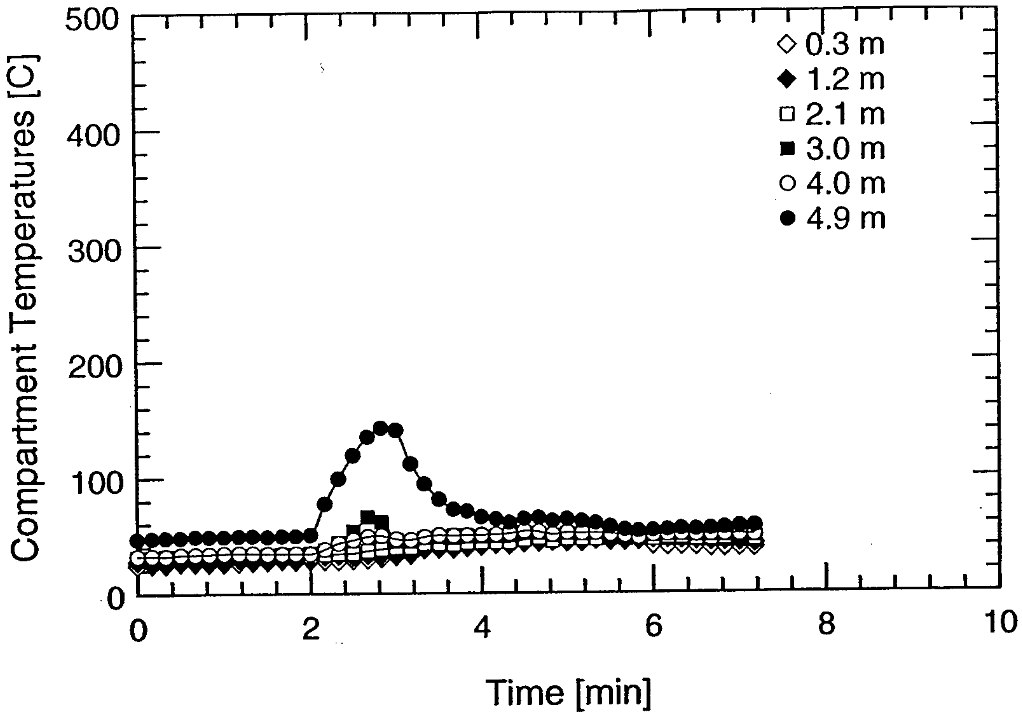


5-22-1

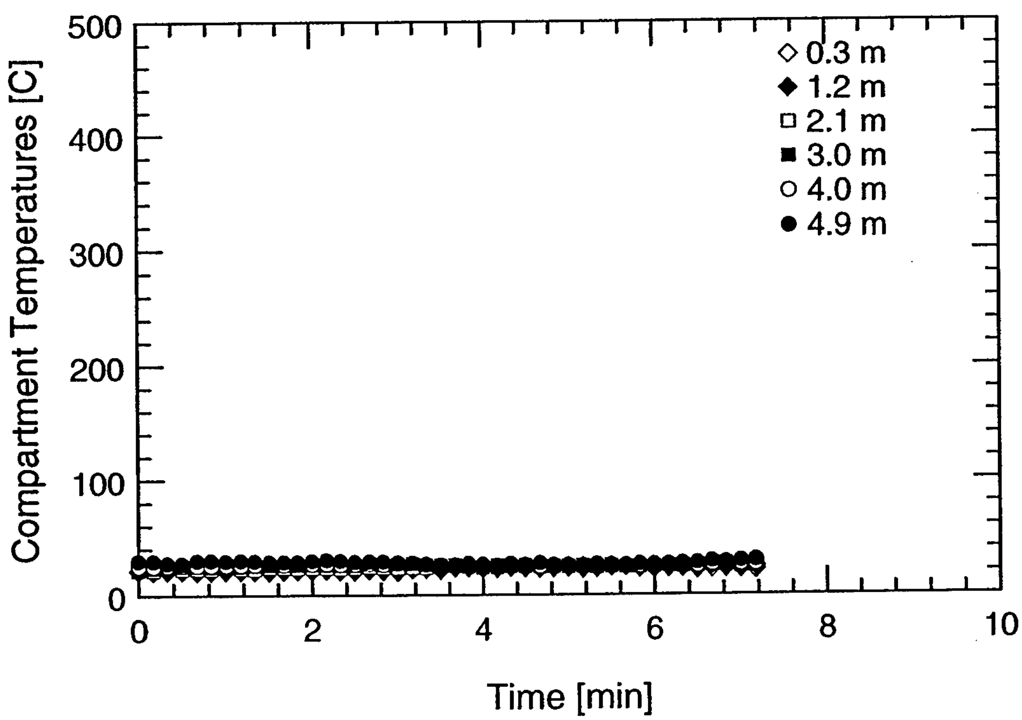


5-27-1

Test #29

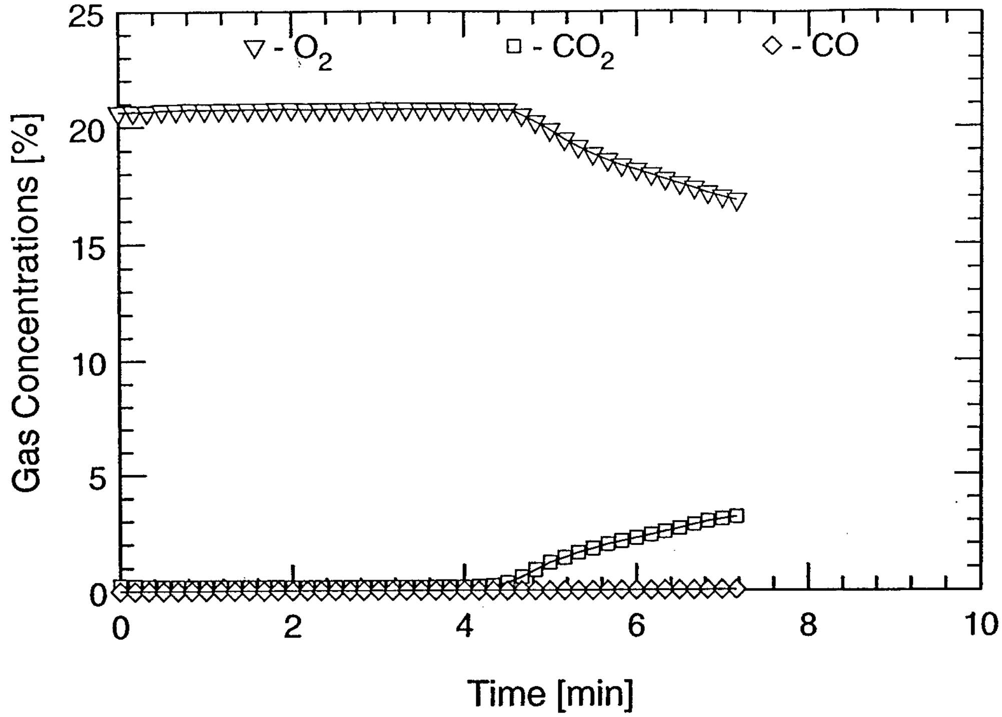


5-27-2

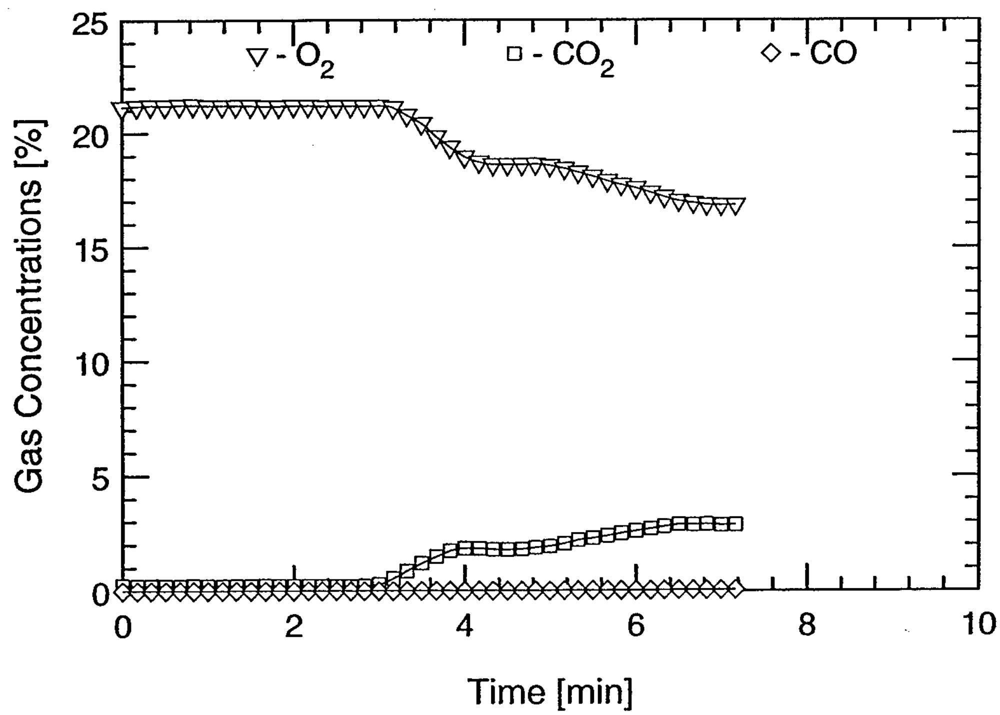


5-35-1

Test #29

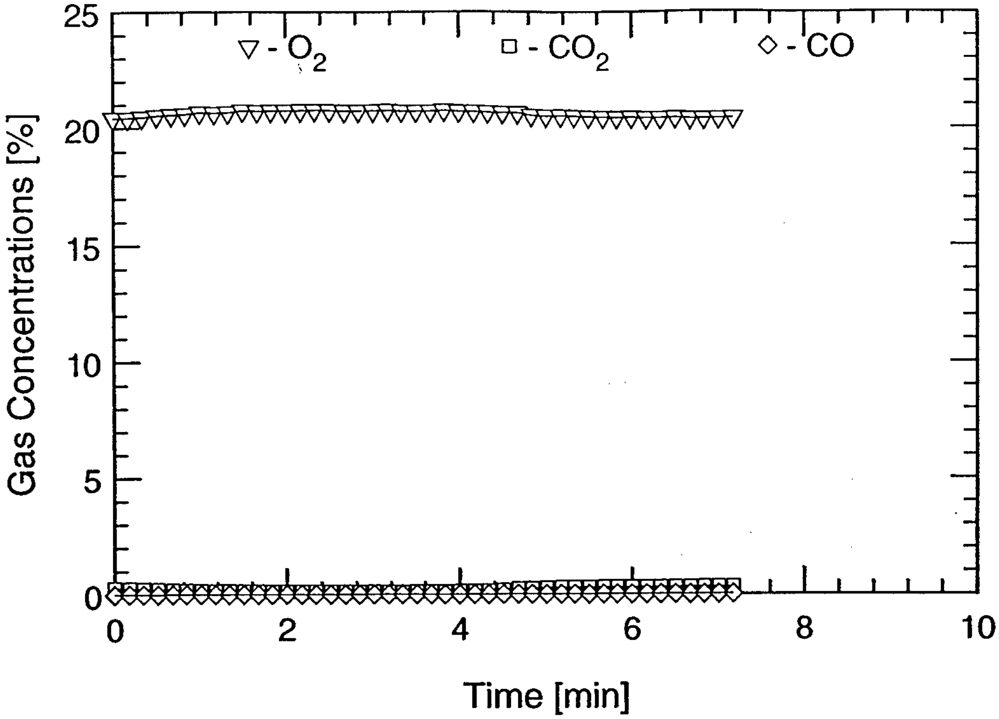


FR 22 - 0.5 m

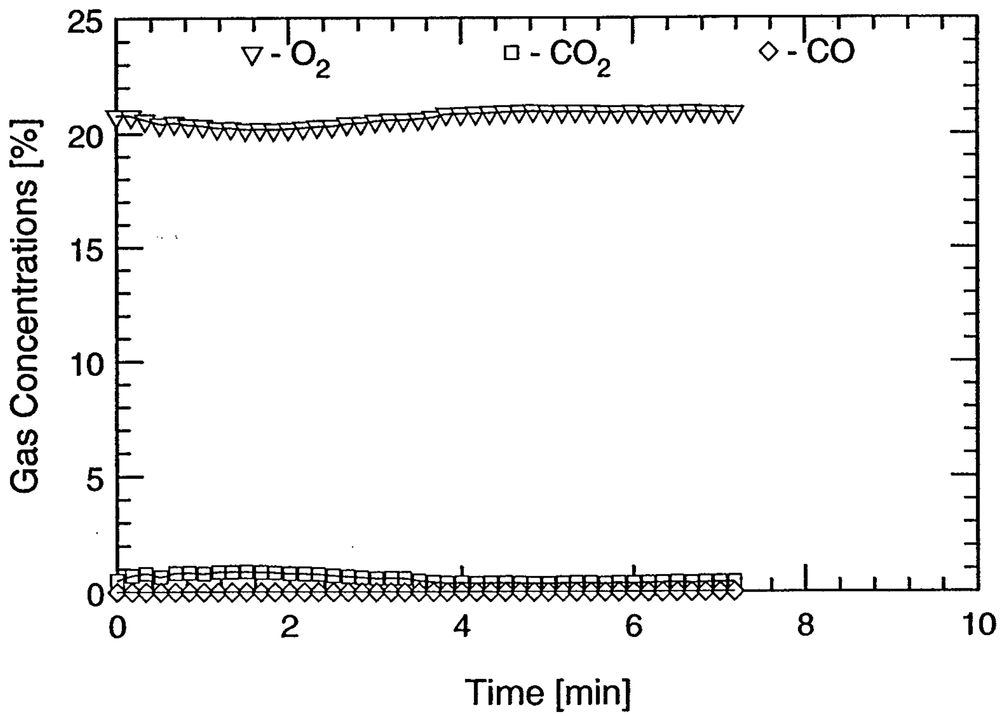


FR 22 - 4.5 m

Test #29

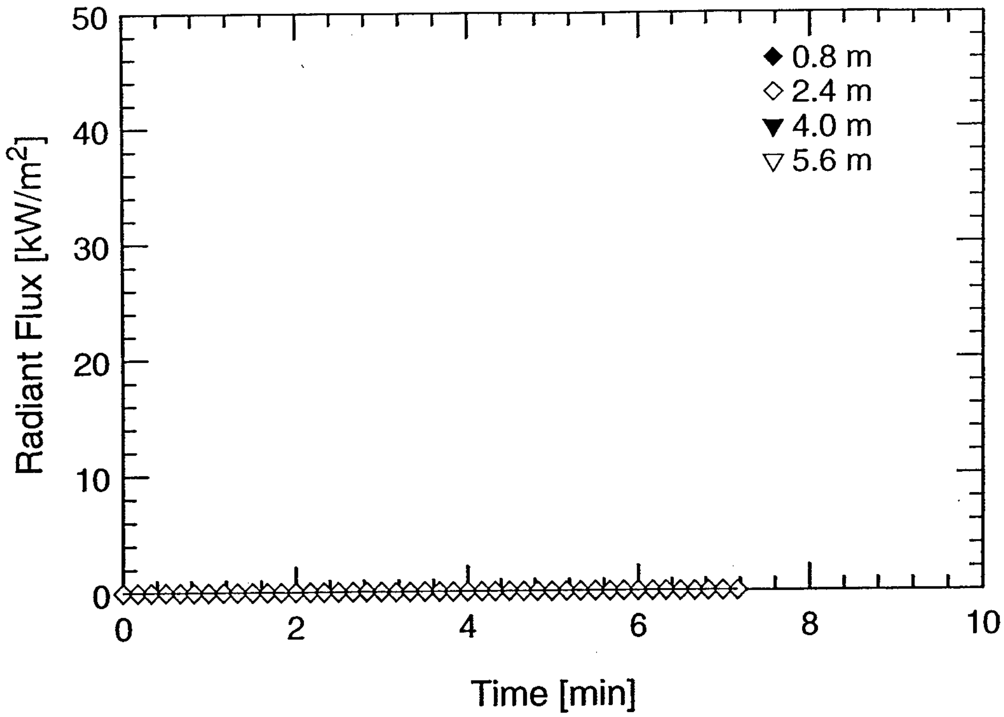


FR 36 - 0.5 m

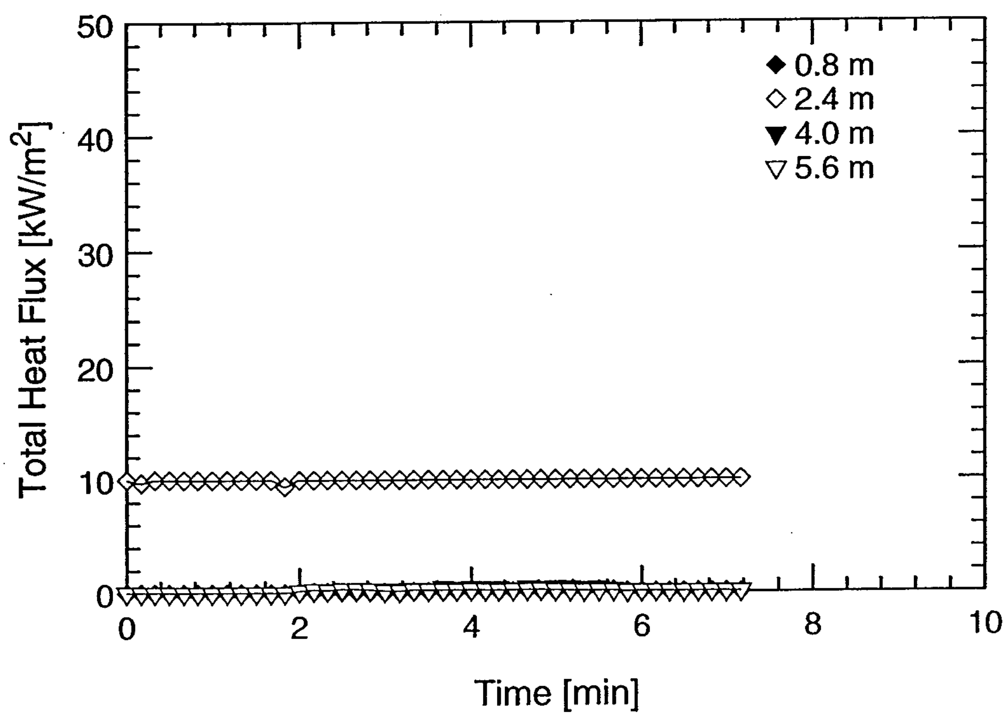


FR 36 - 4.5 m

Test #29

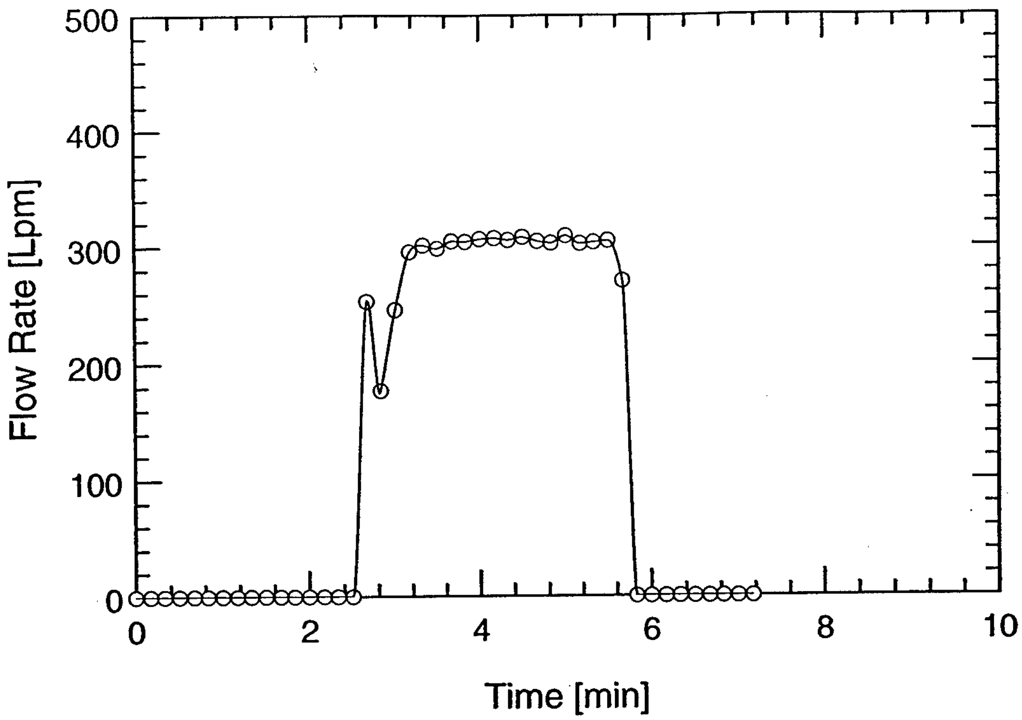


FR 22

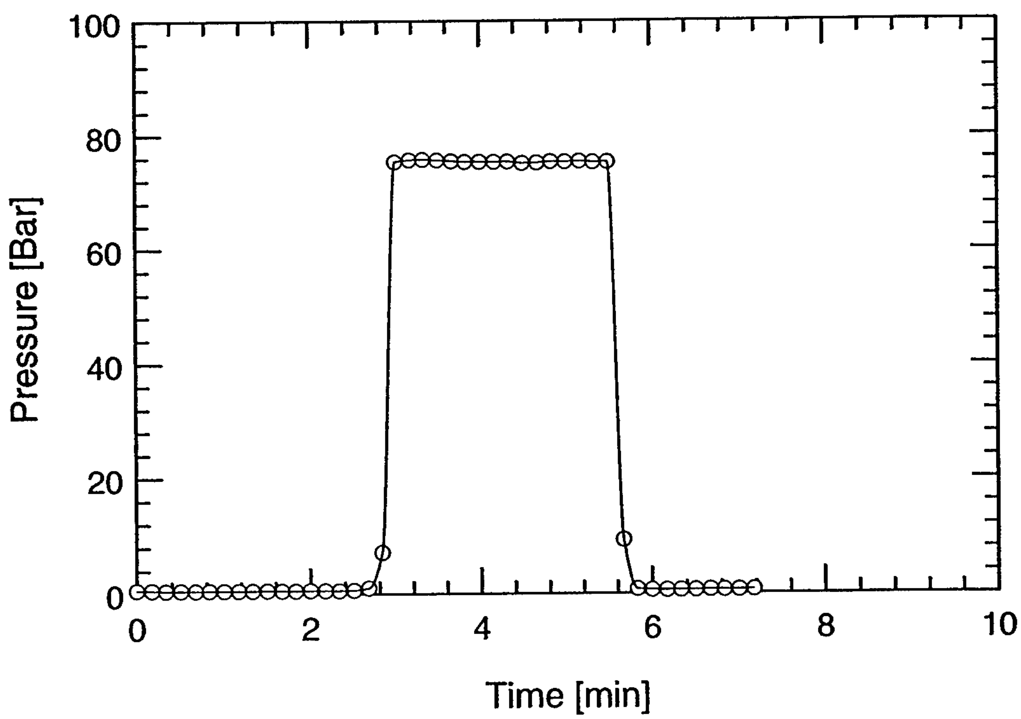


FR 22

Test #29

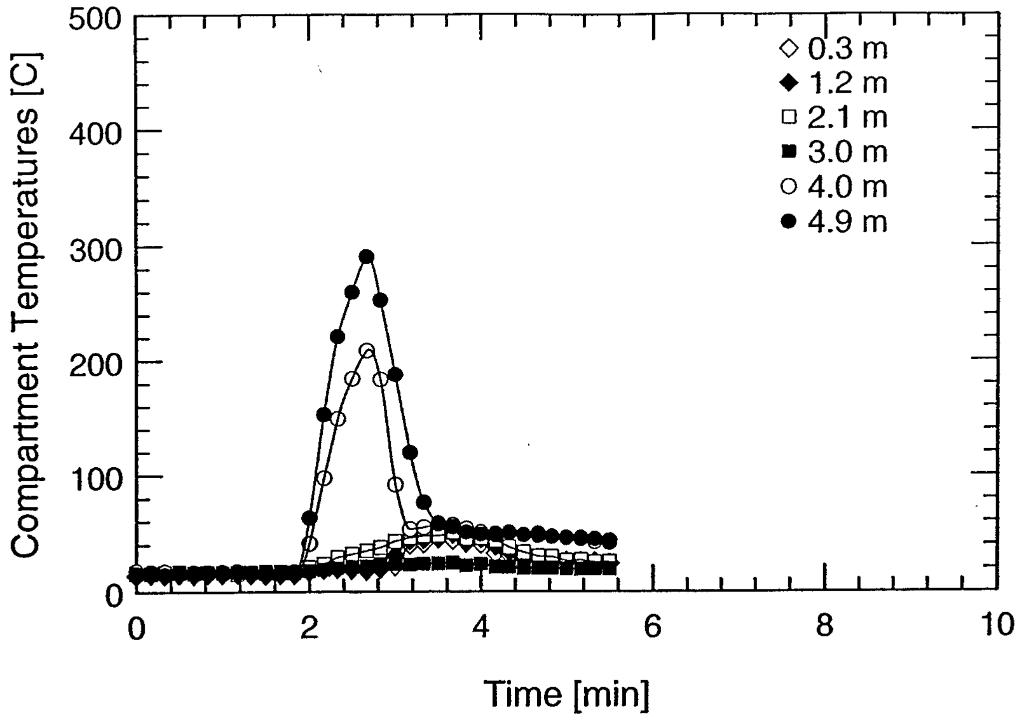


Water Mist System Flow Rate

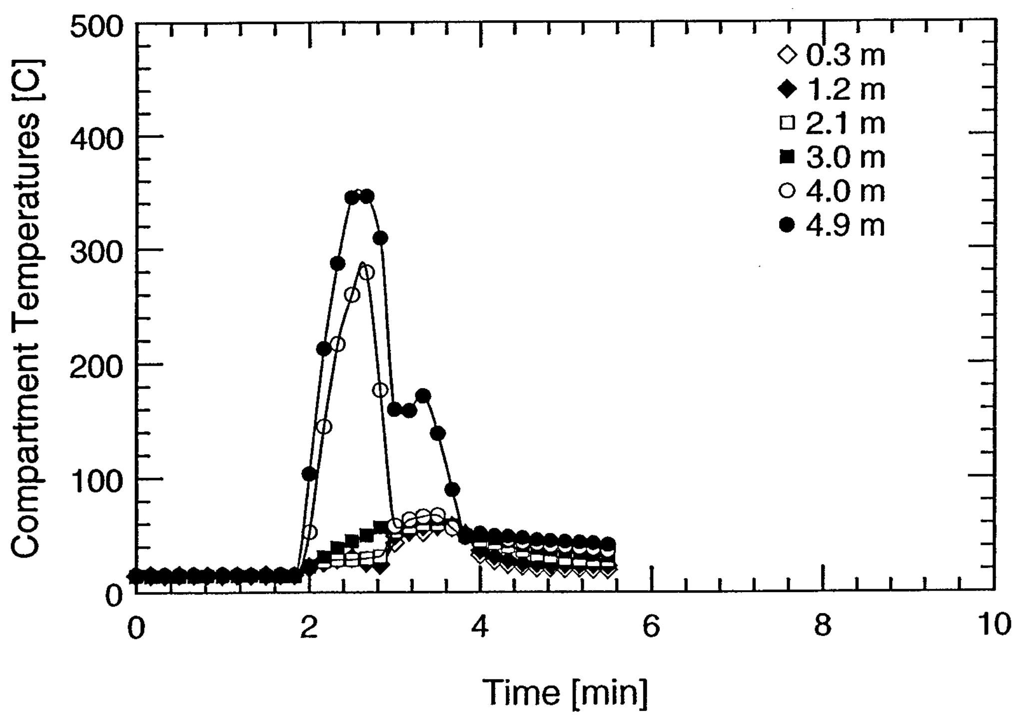


Water Mist System Pressure

Test #29

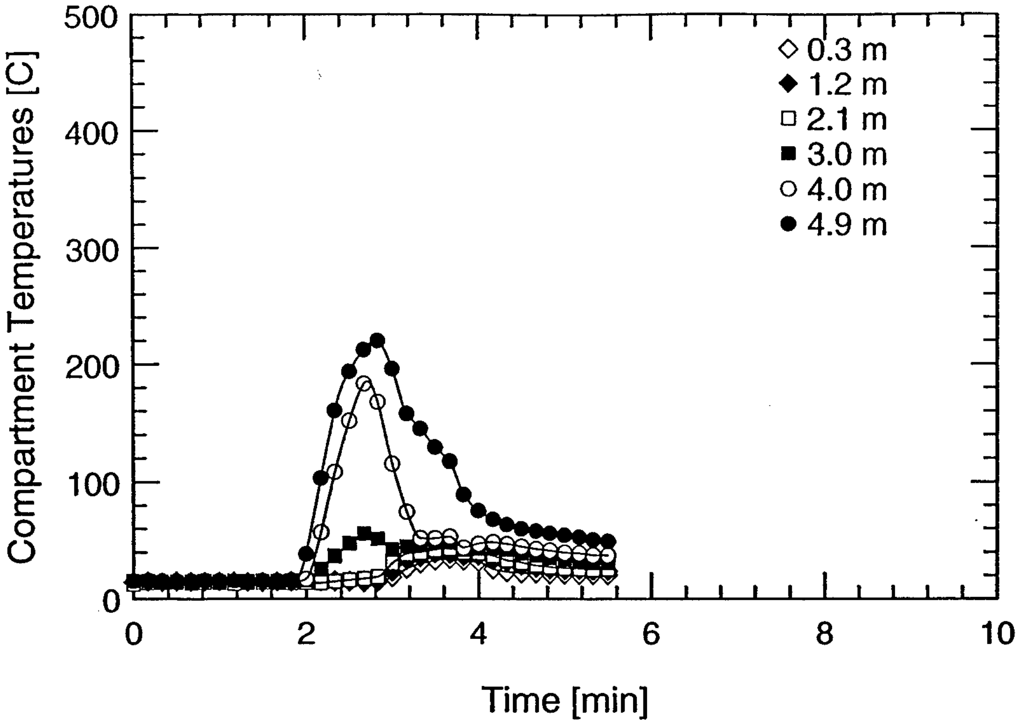


5-22-1

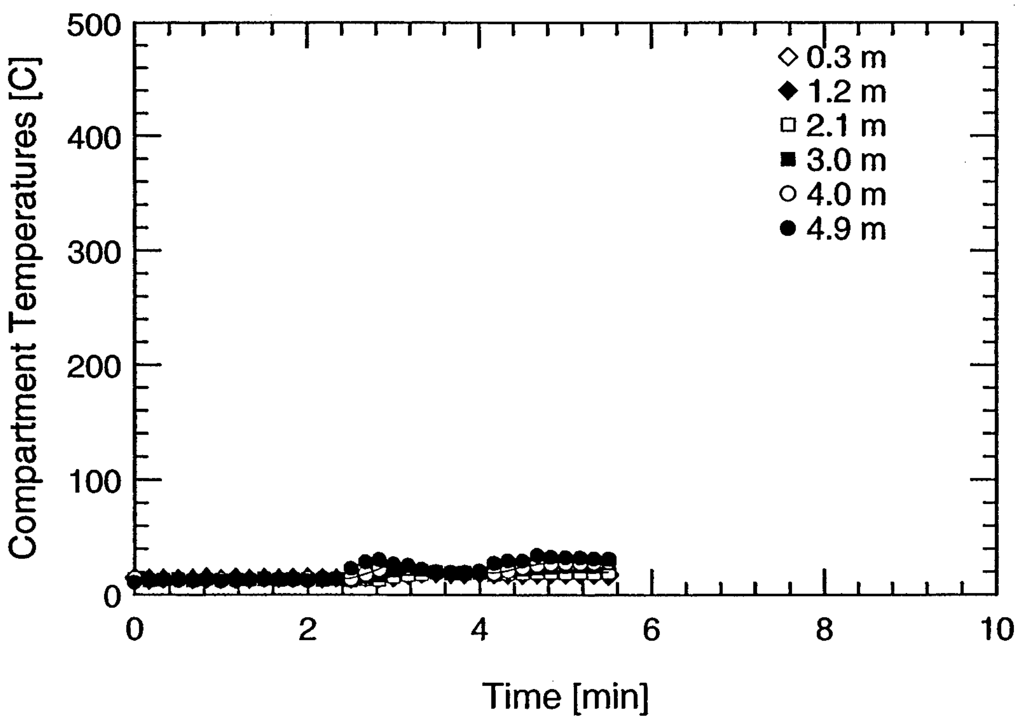


5-27-1

Test #30

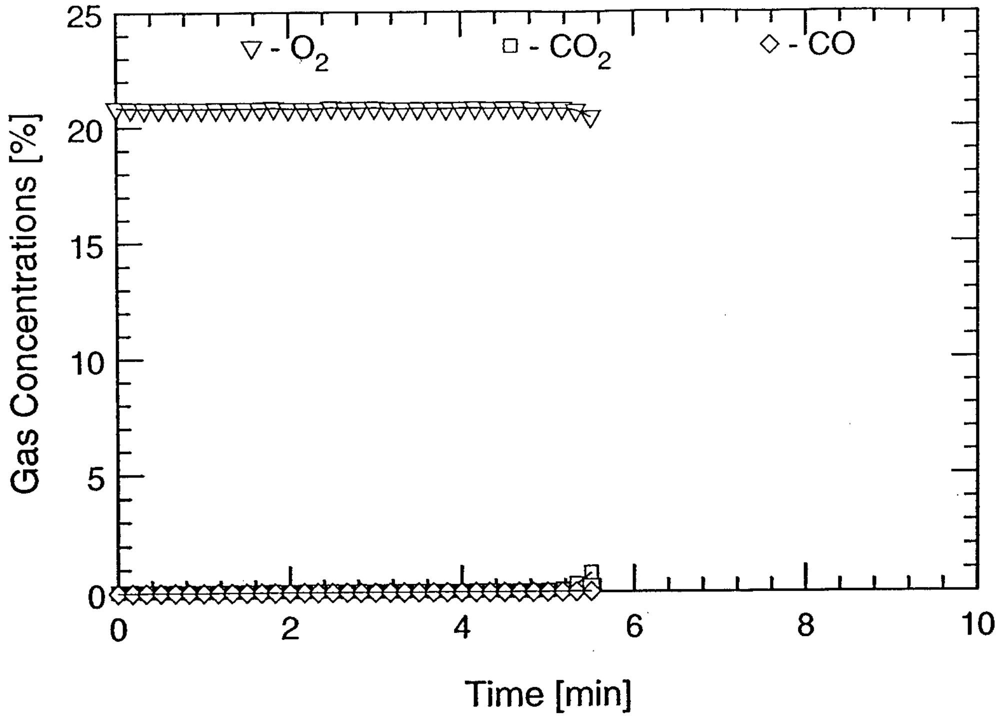


5-27-2

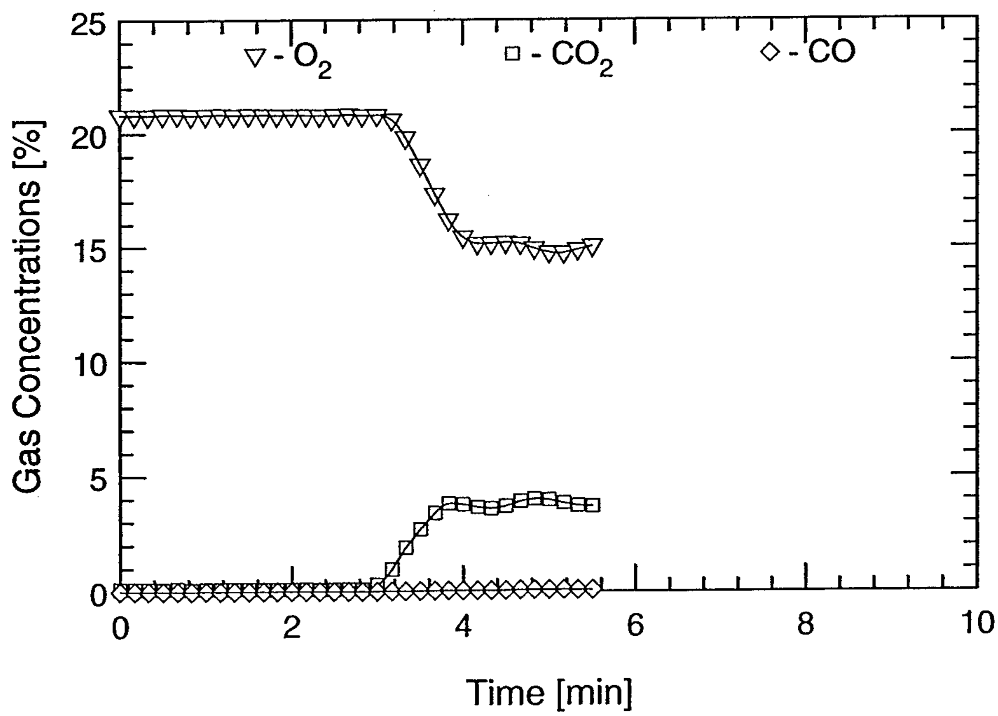


5-35-1

Test #30

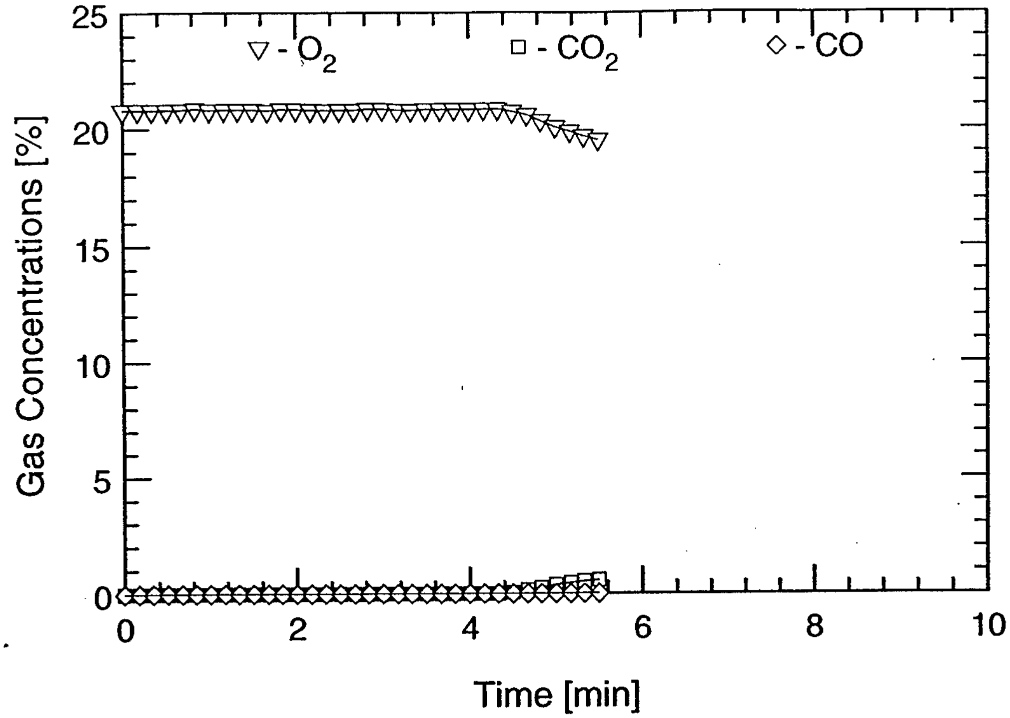


FR 22 - 0.5 m

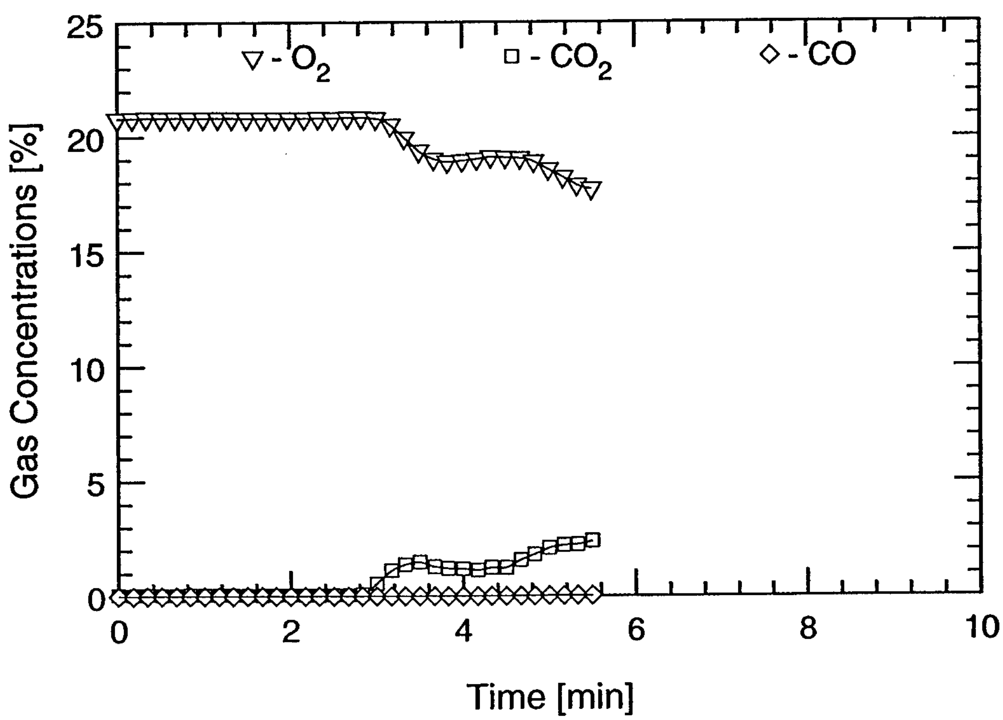


FR 22 - 4.5 m

Test #30

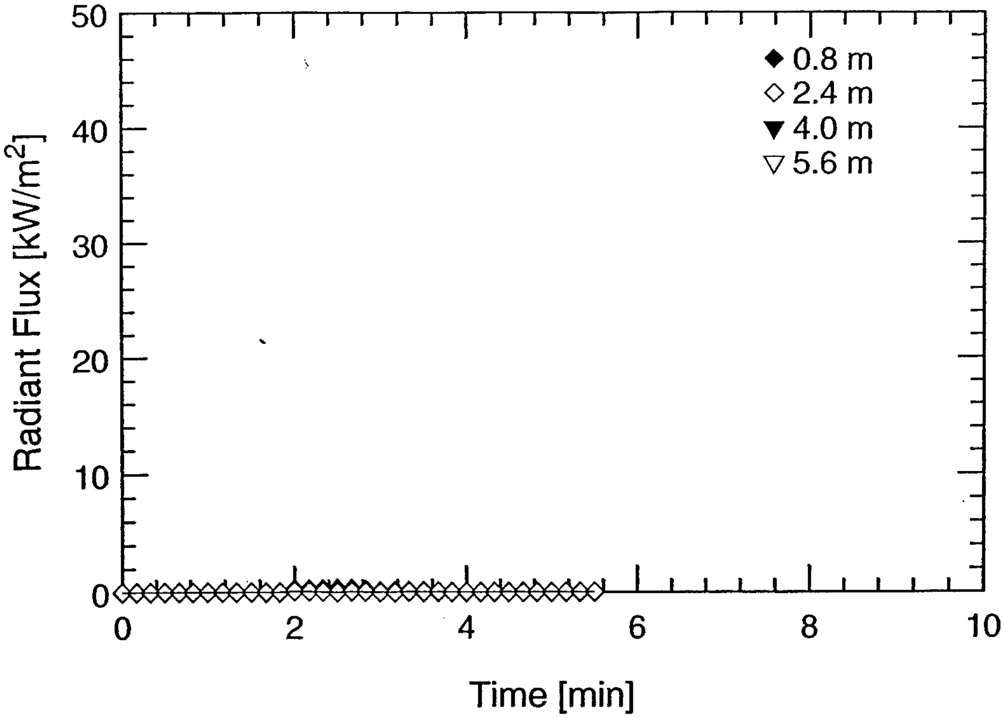


FR 36 - 0.5 m

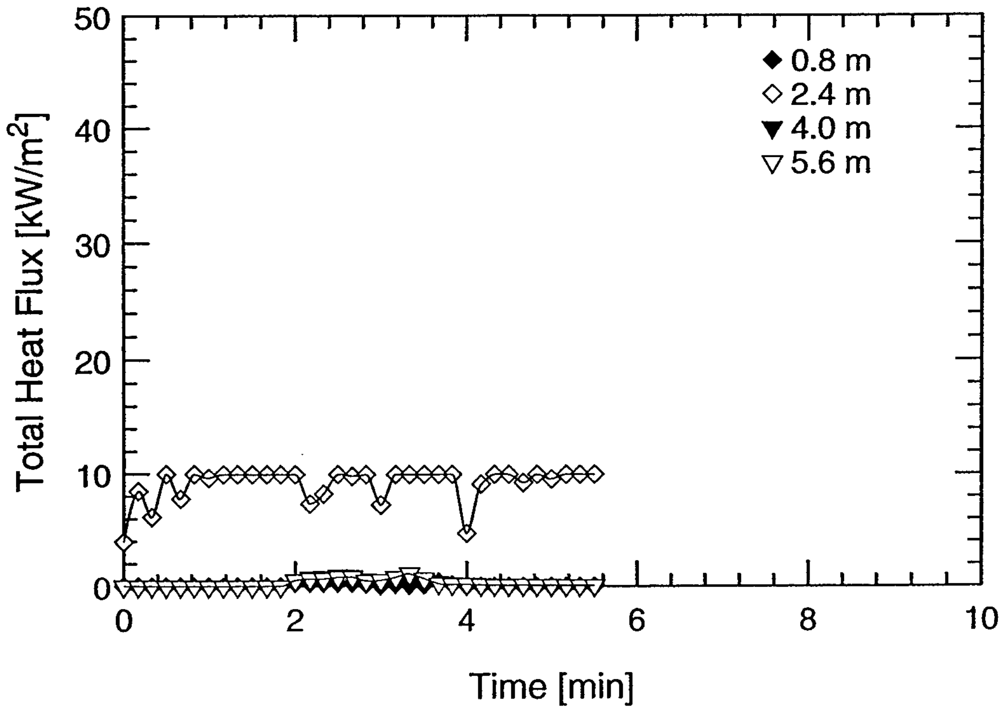


FR 36 - 4.5 m

Test #30

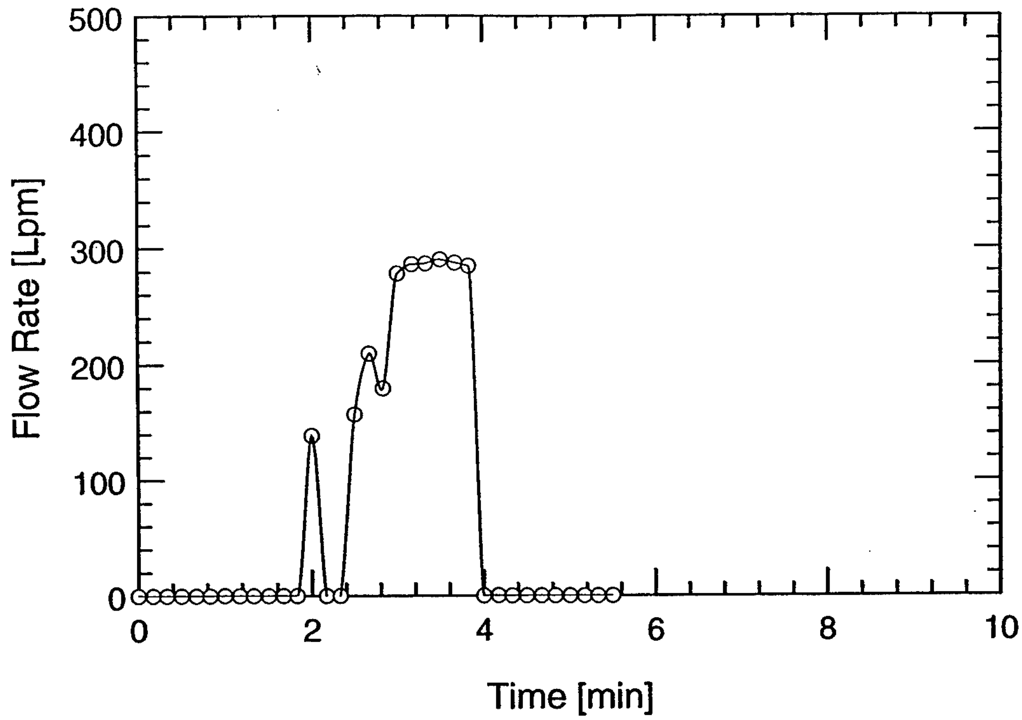


FR 22

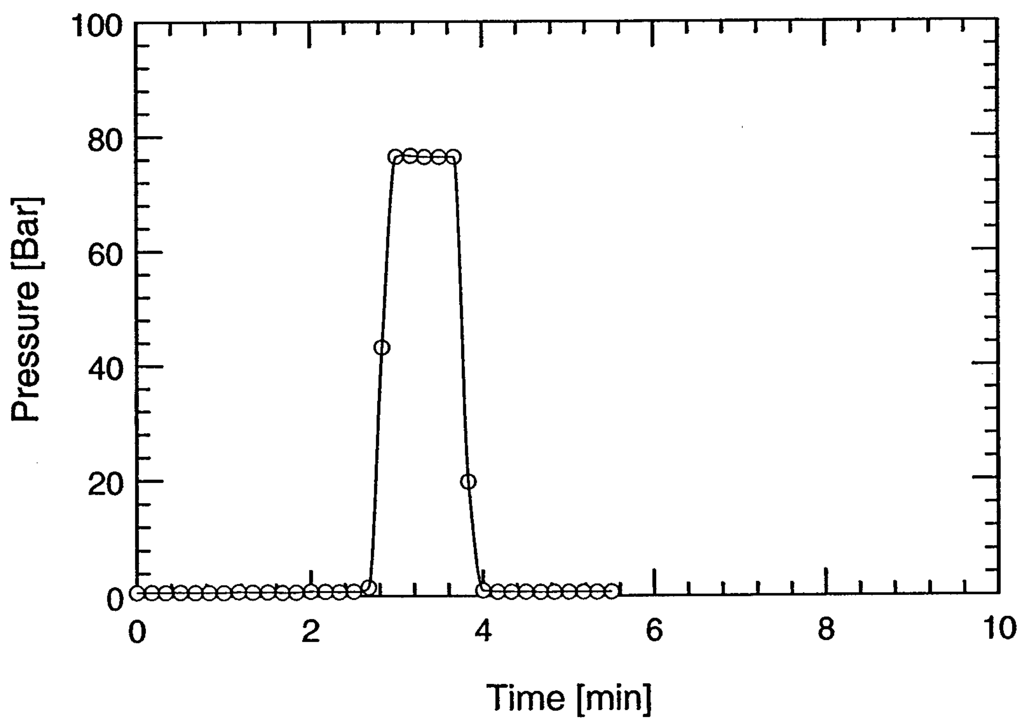


FR 22

Test #30

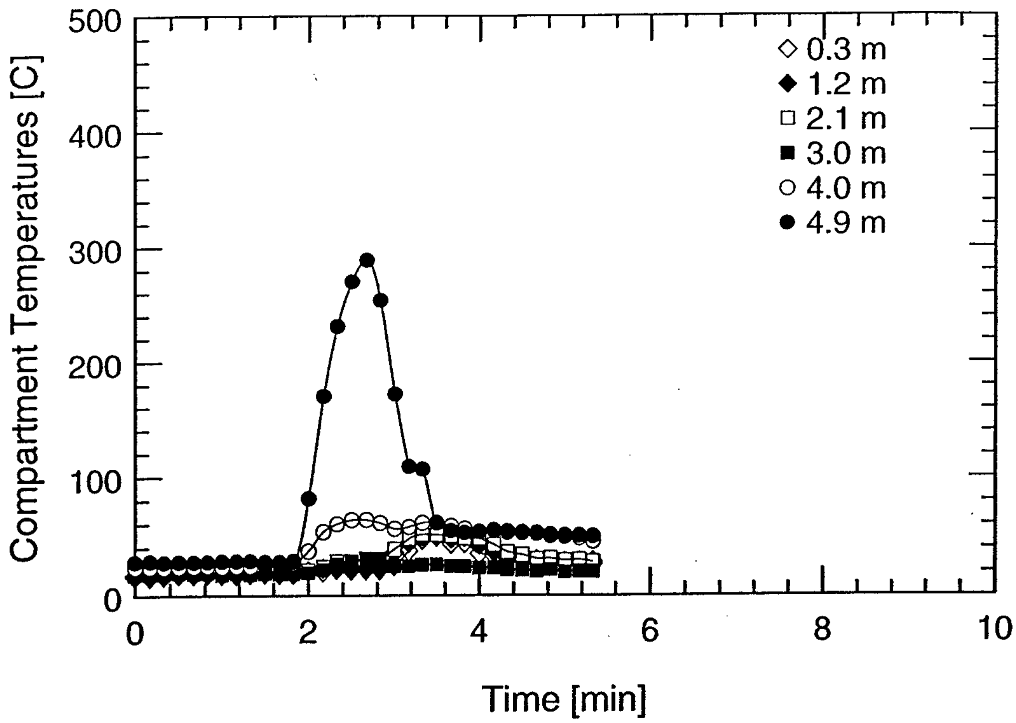


Water Mist System Flow Rate

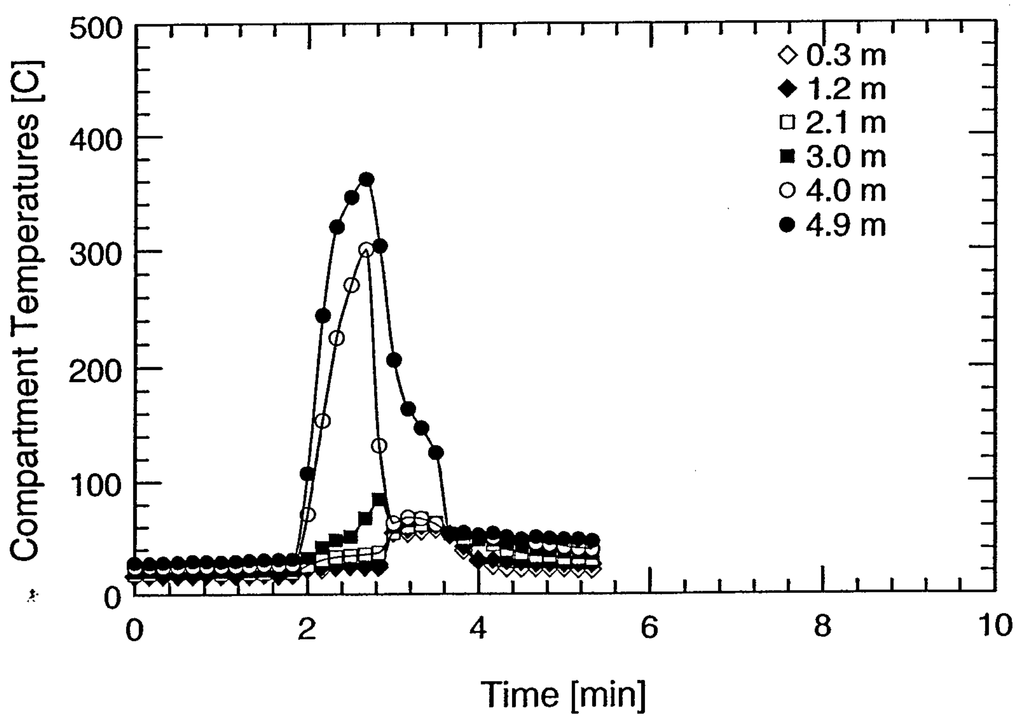


Water Mist System Pressure

Test #30

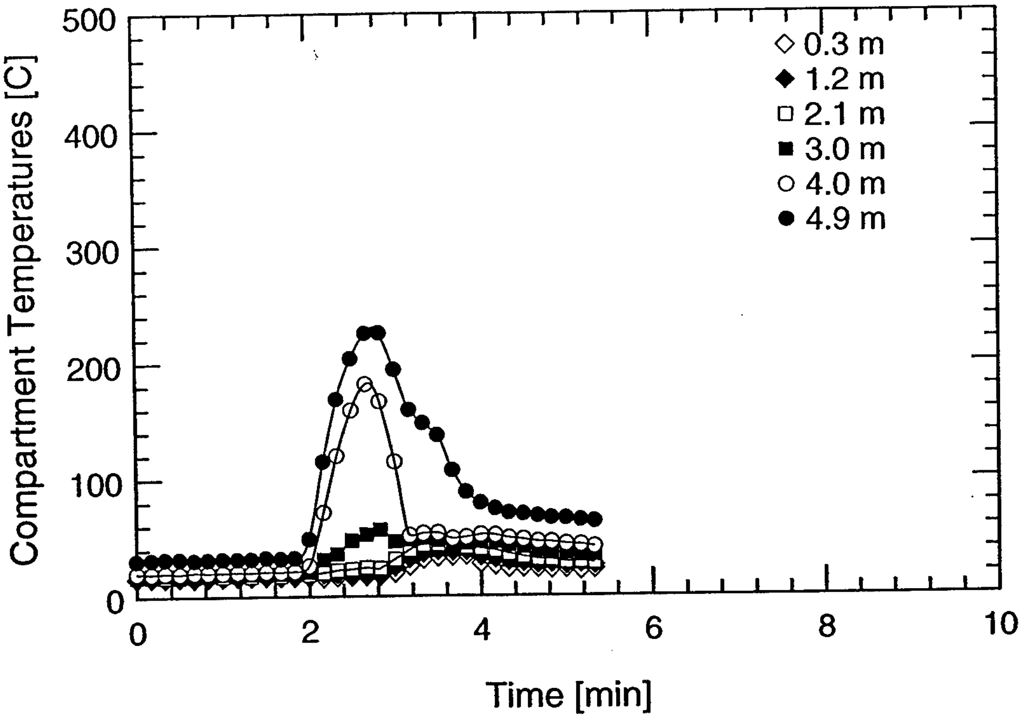


5-22-1

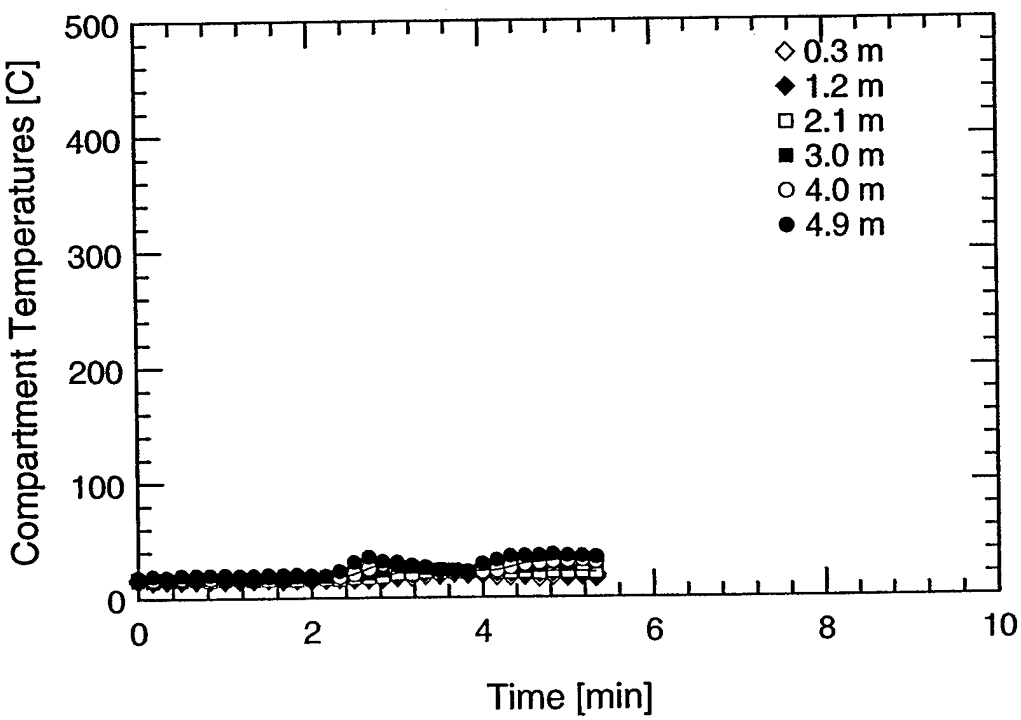


5-27-1

Test #31

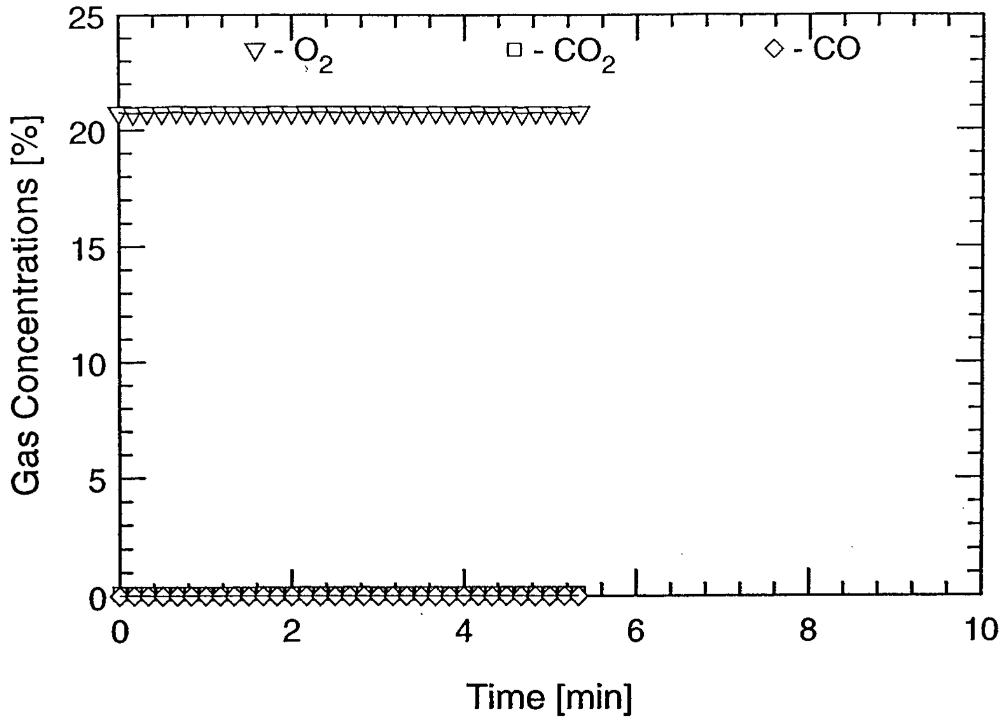


5-27-2

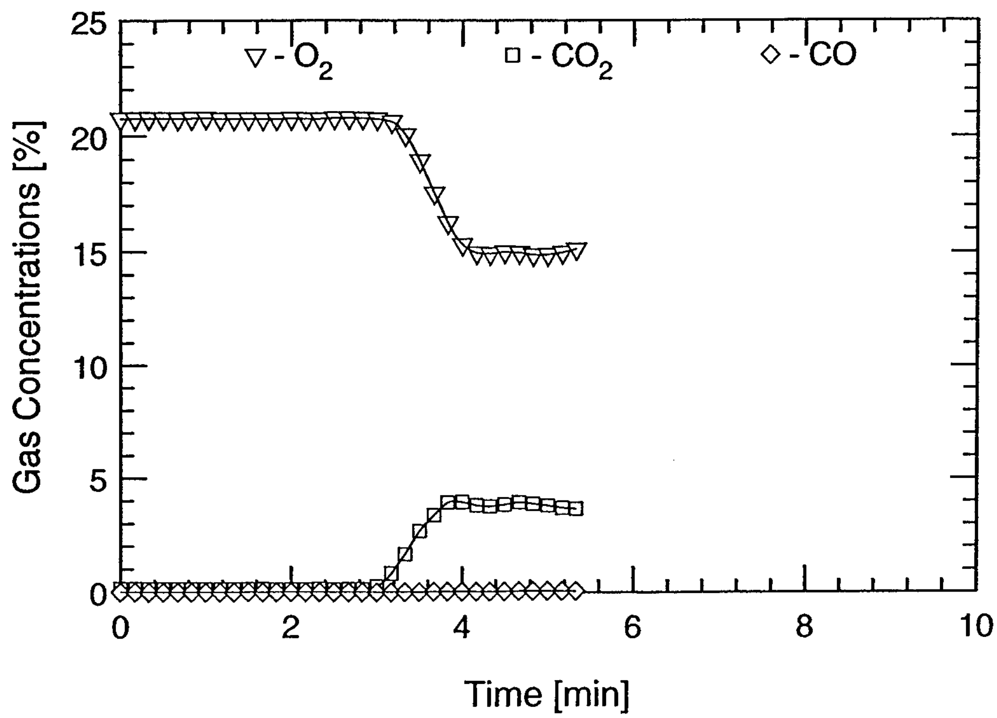


5-35-1

Test #31

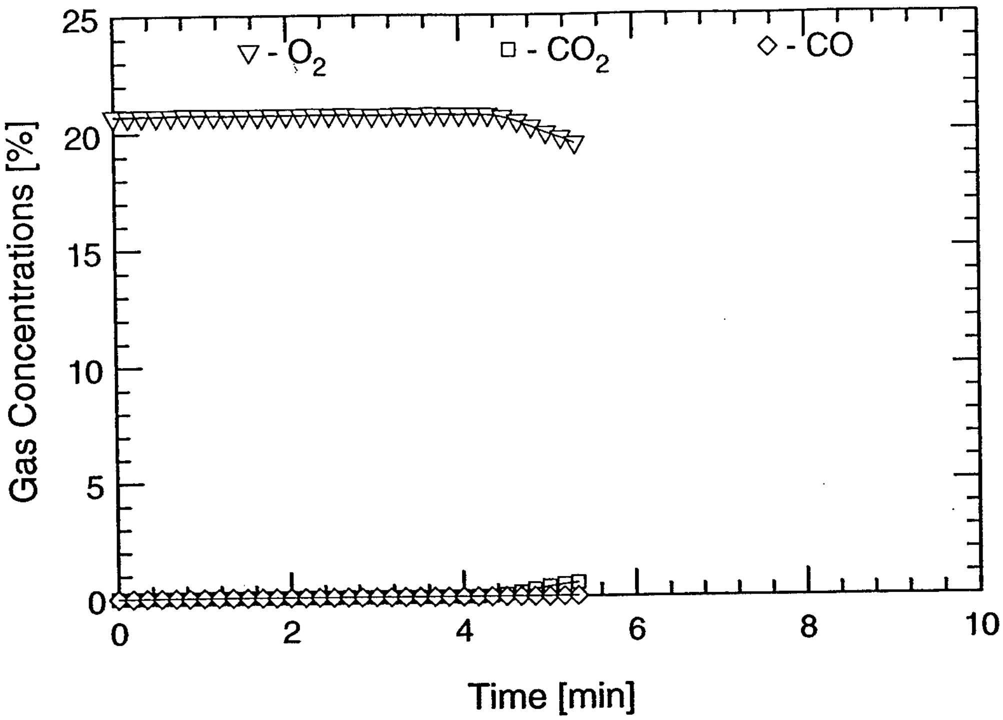


FR 22 - 0.5 m

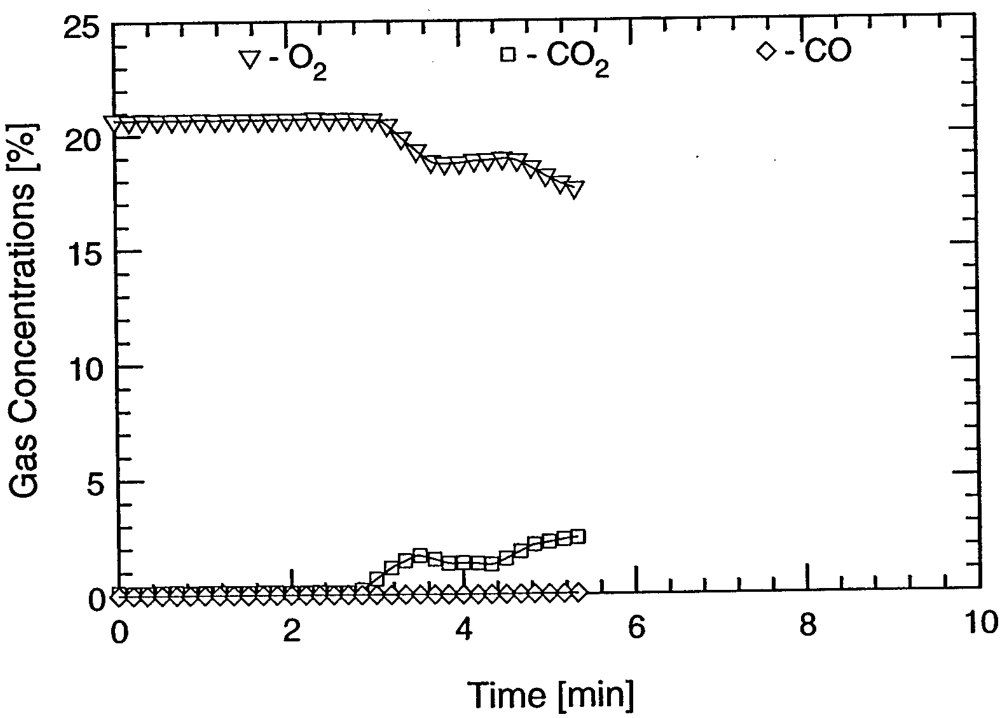


FR 22 - 4.5 m

Test #31

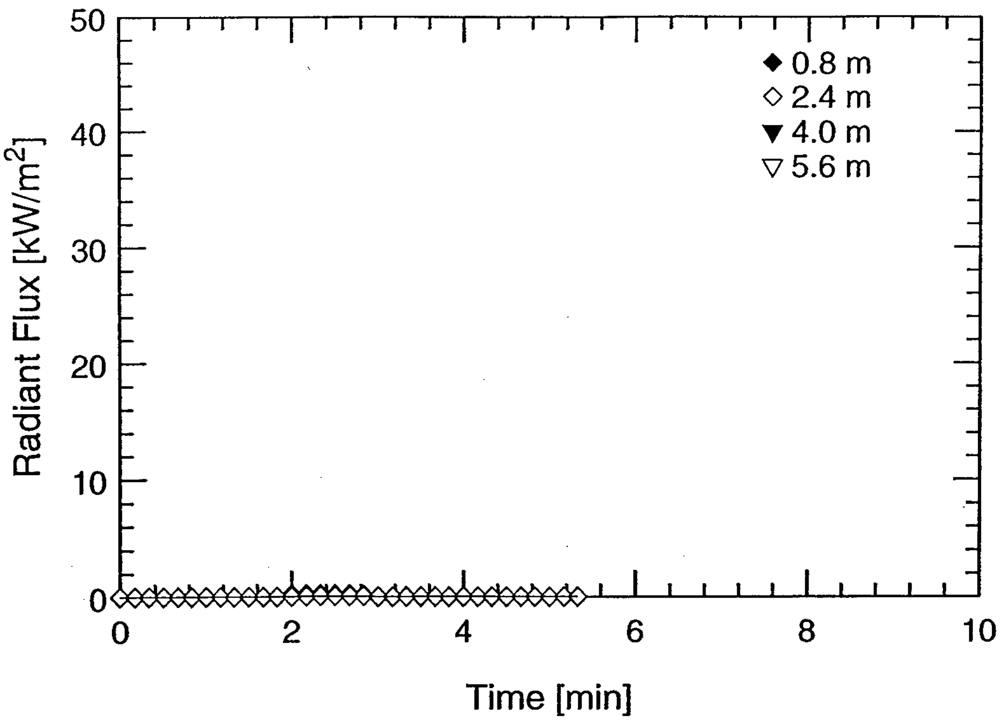


FR 36 - 0.5 m

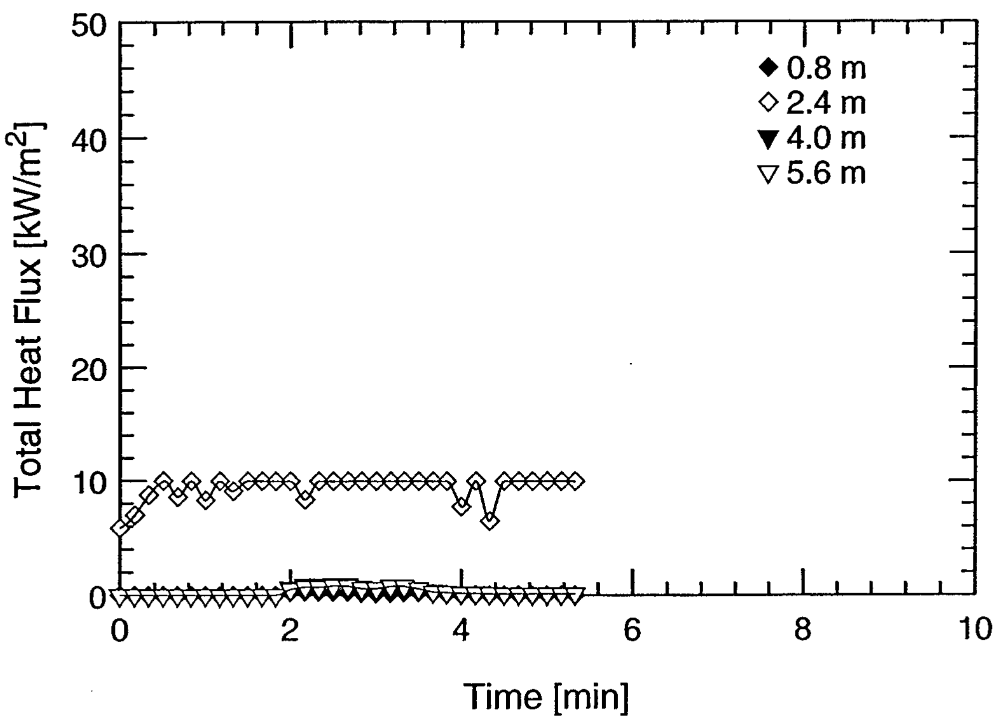


FR 36 - 4.5 m

Test #31

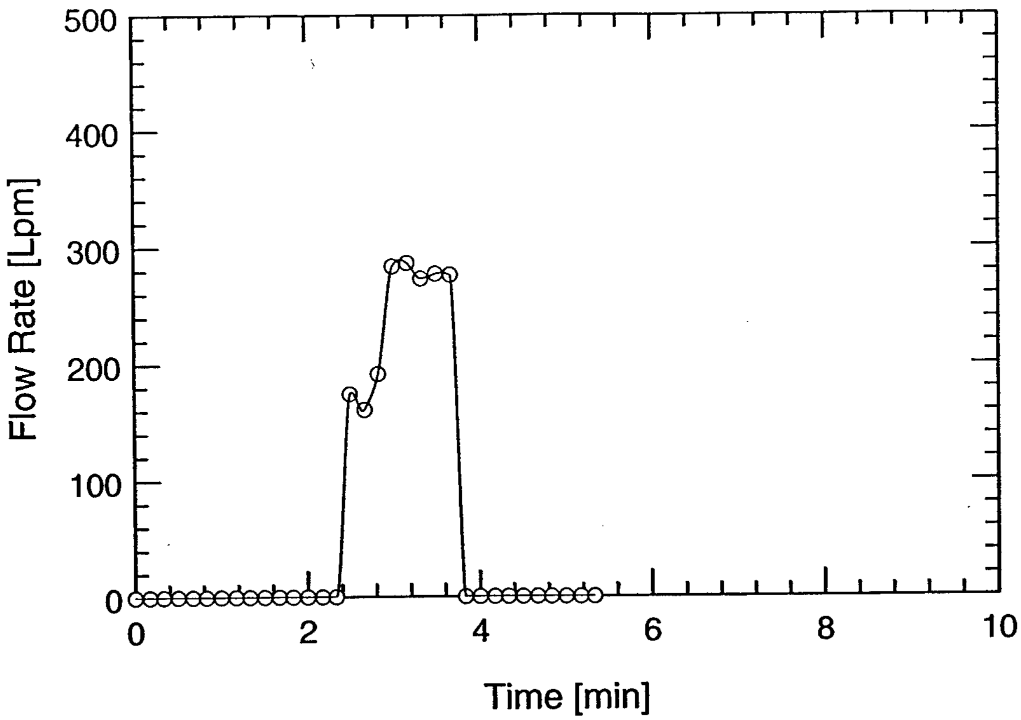


FR 22

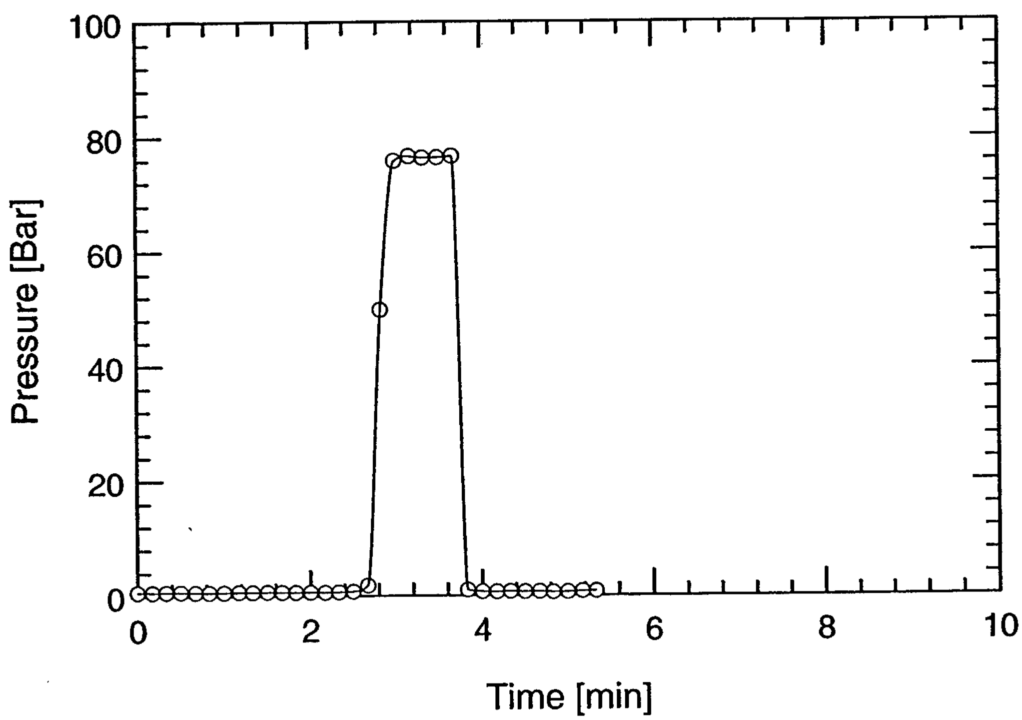


FR 22

Test #31

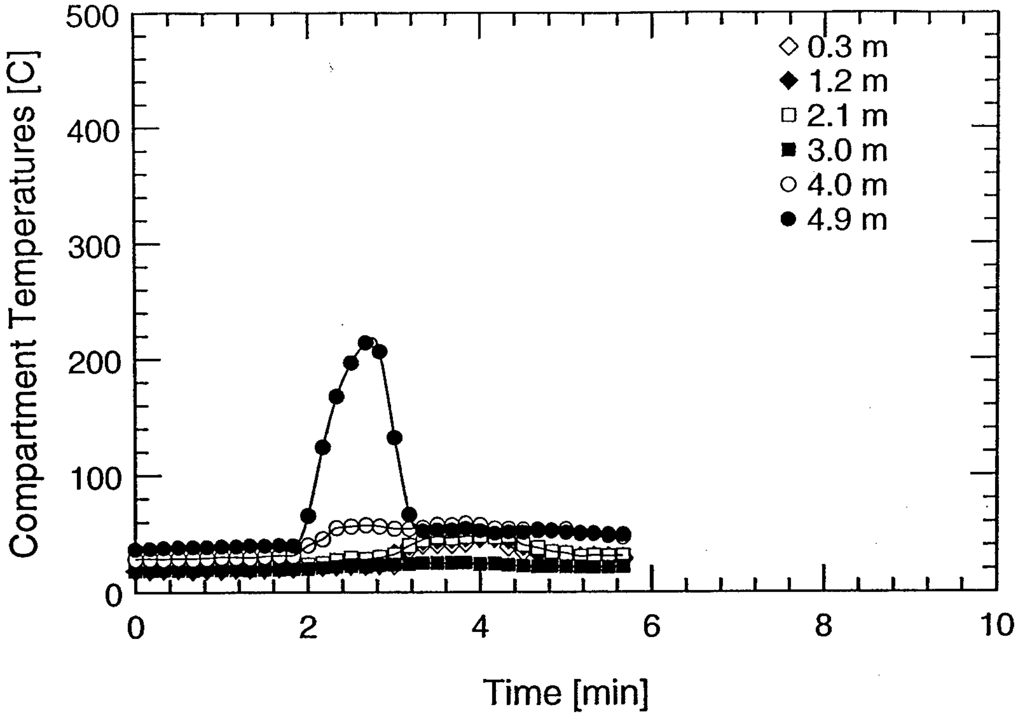


Water Mist System Flow Rate

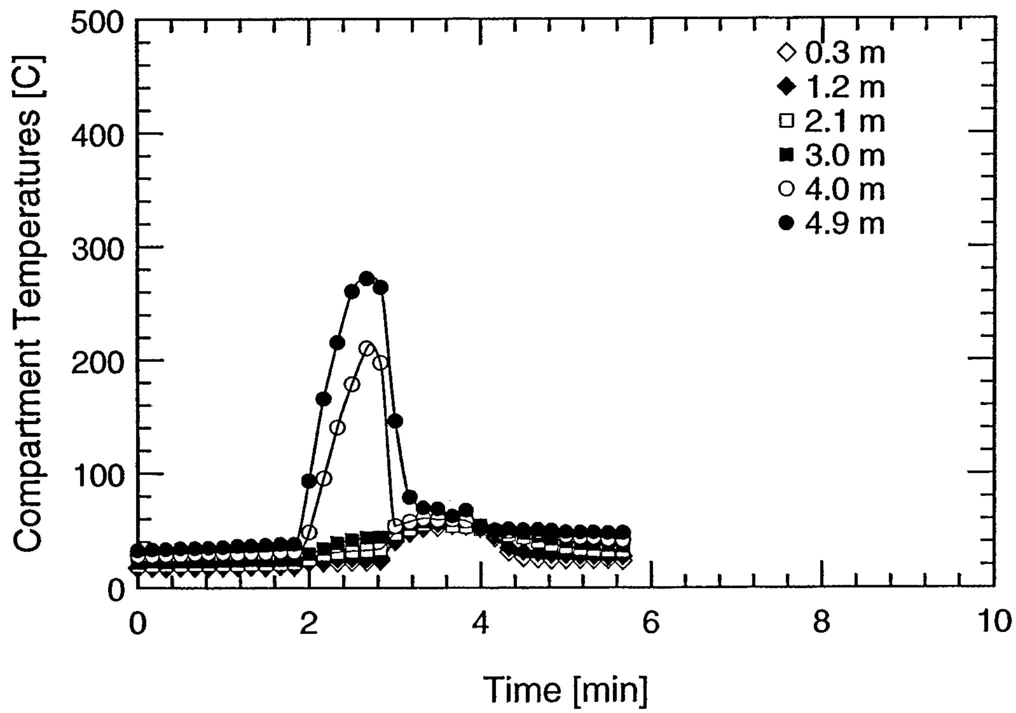


Water Mist System Pressure

Test #31

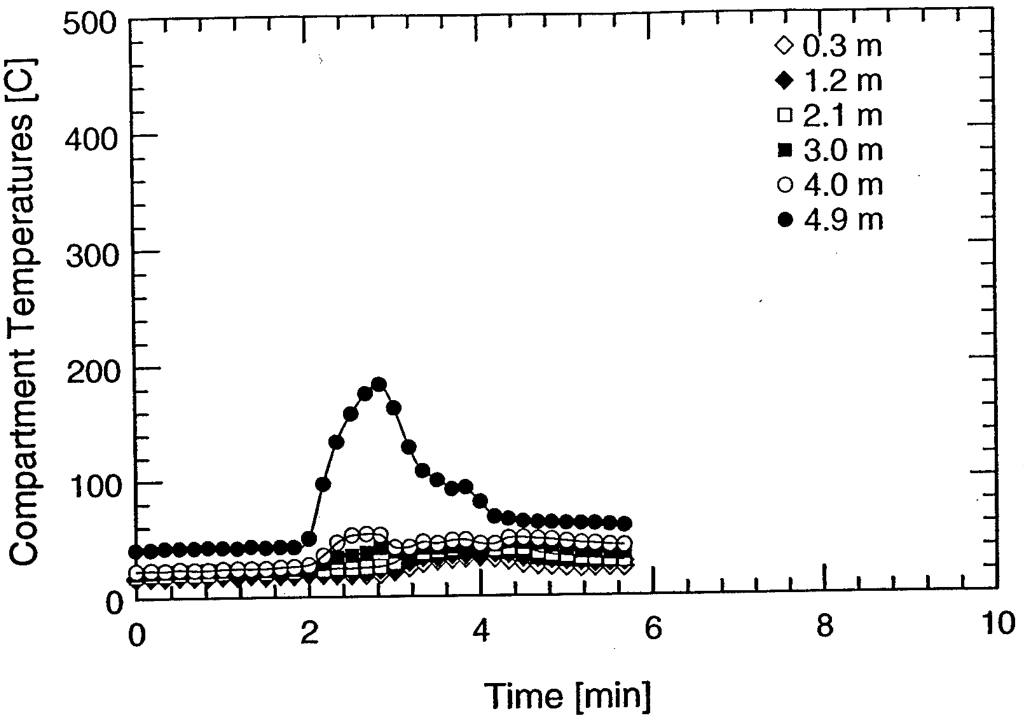


5-22-1

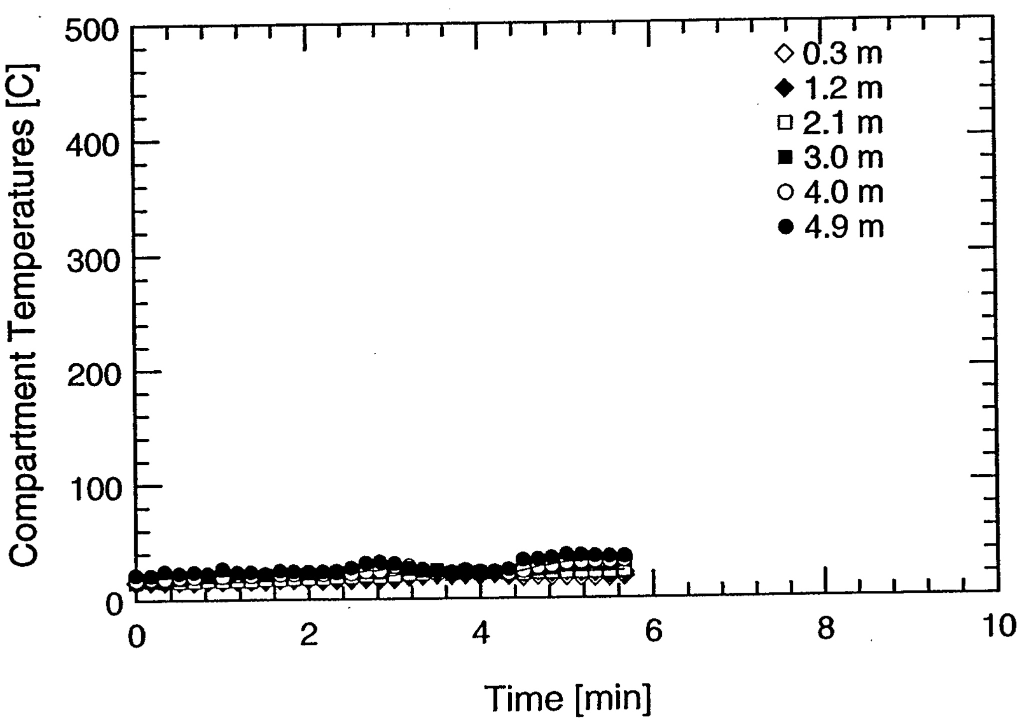


5-27-1

Test #32

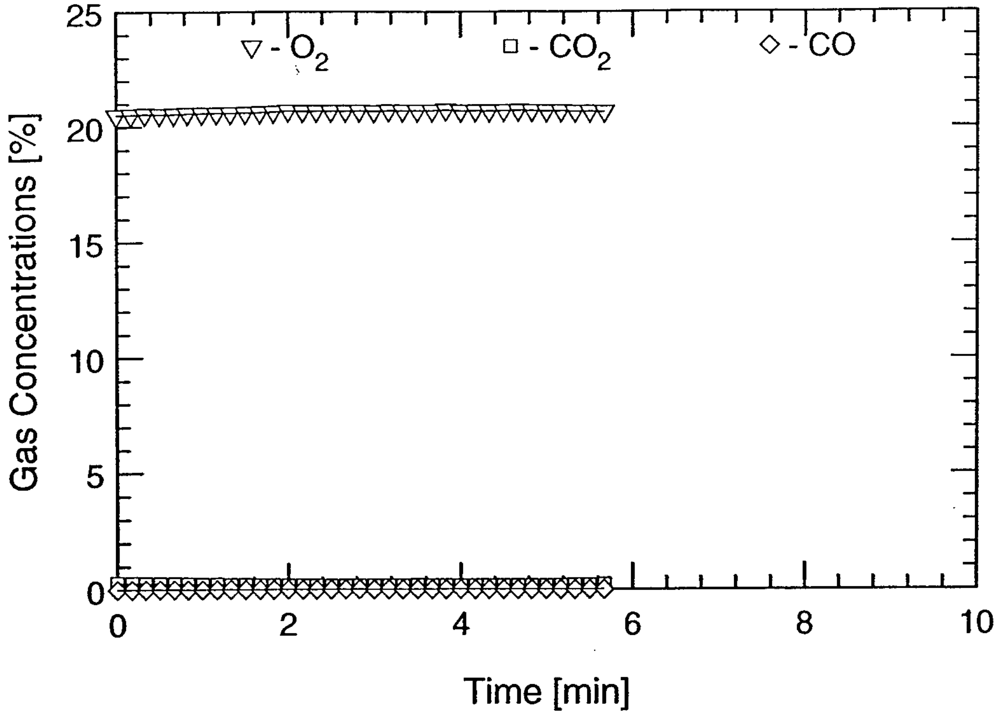


5-27-2

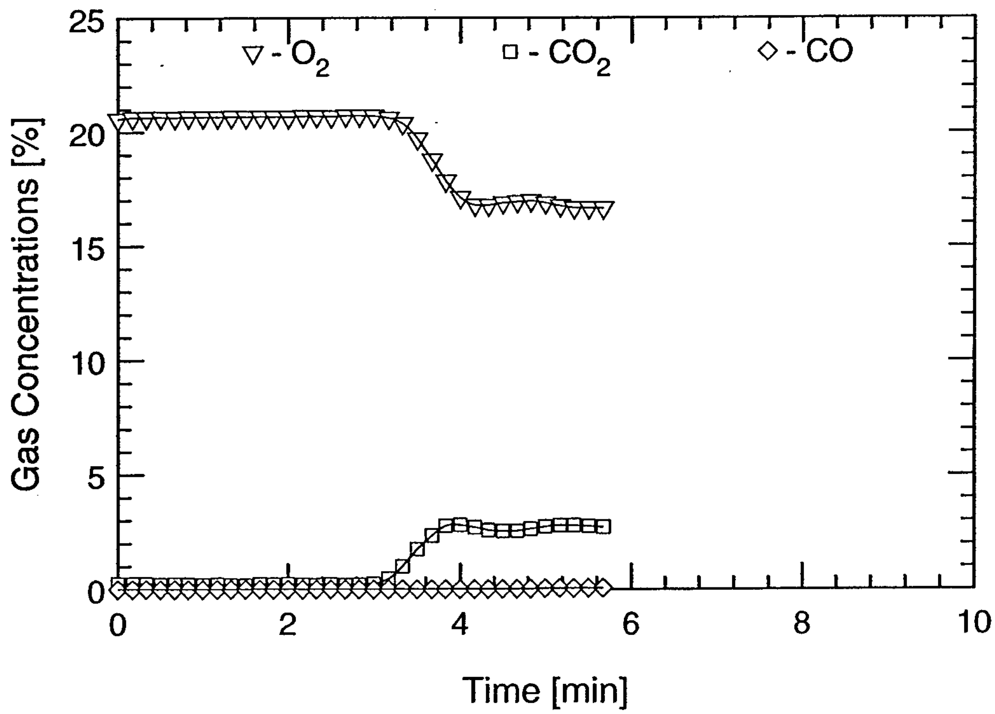


5-35-1

Test #32

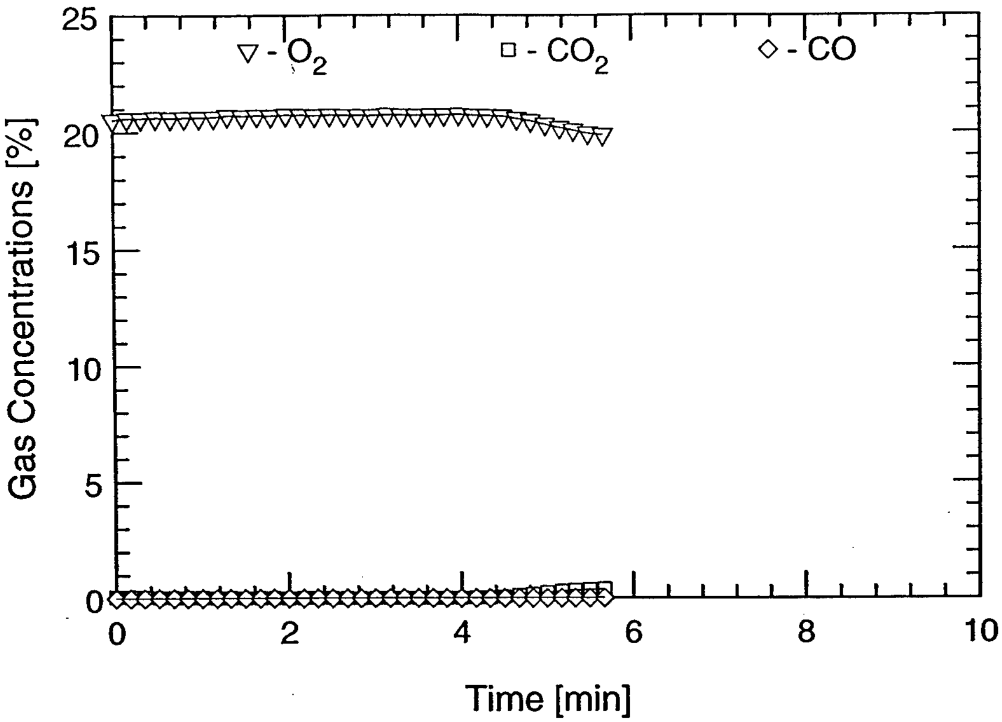


FR 22 - 0.5 m

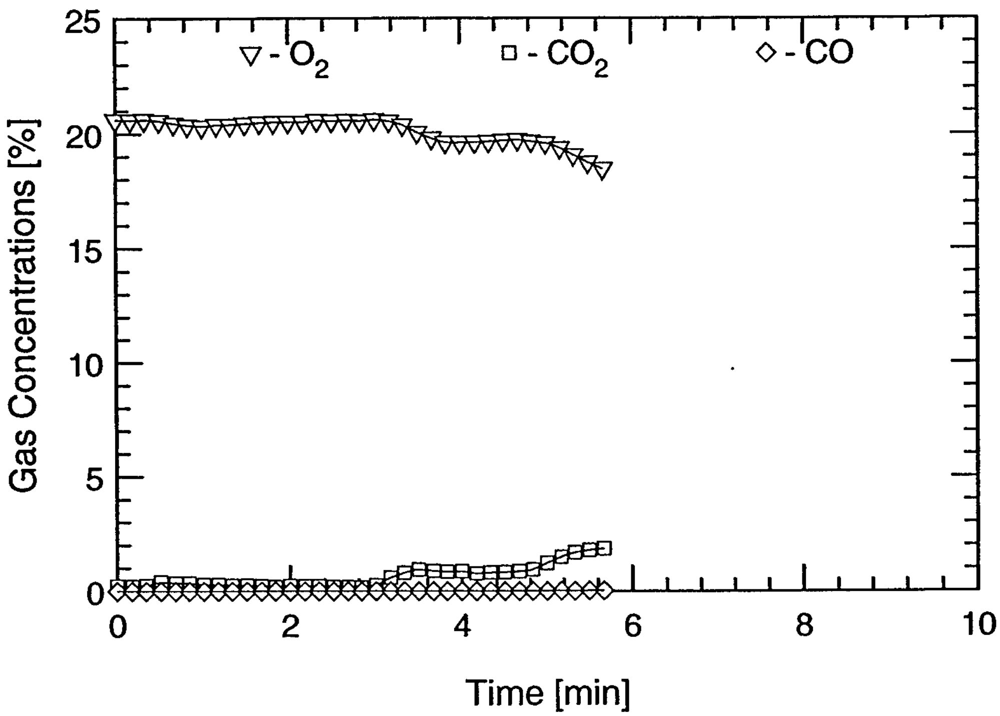


FR 22 - 4.5 m

Test #32

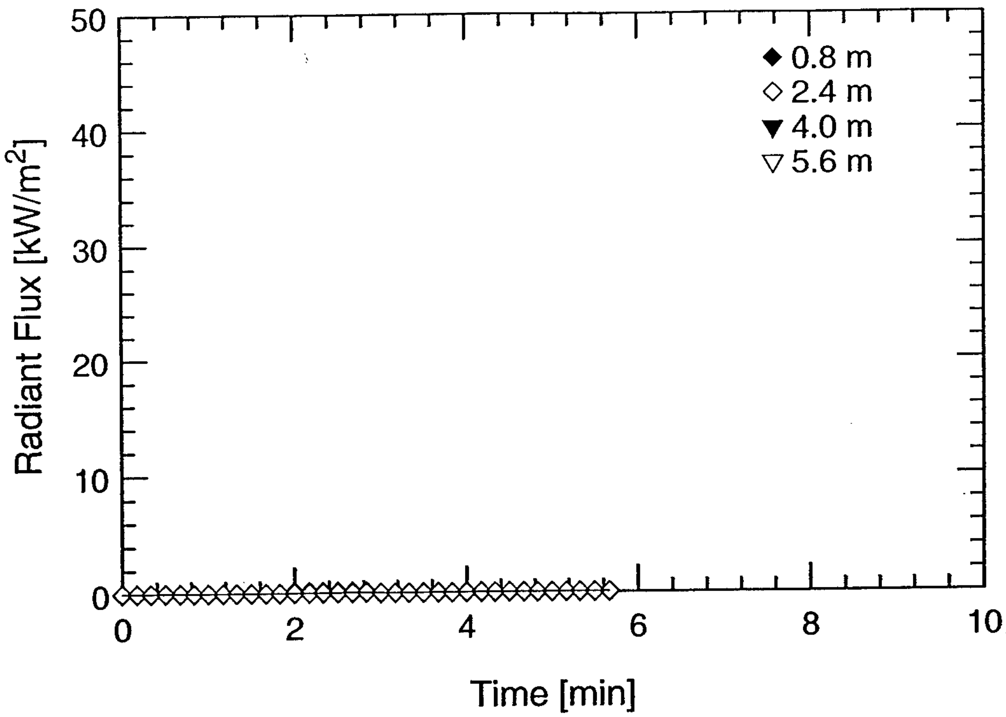


FR 36 - 0.5 m

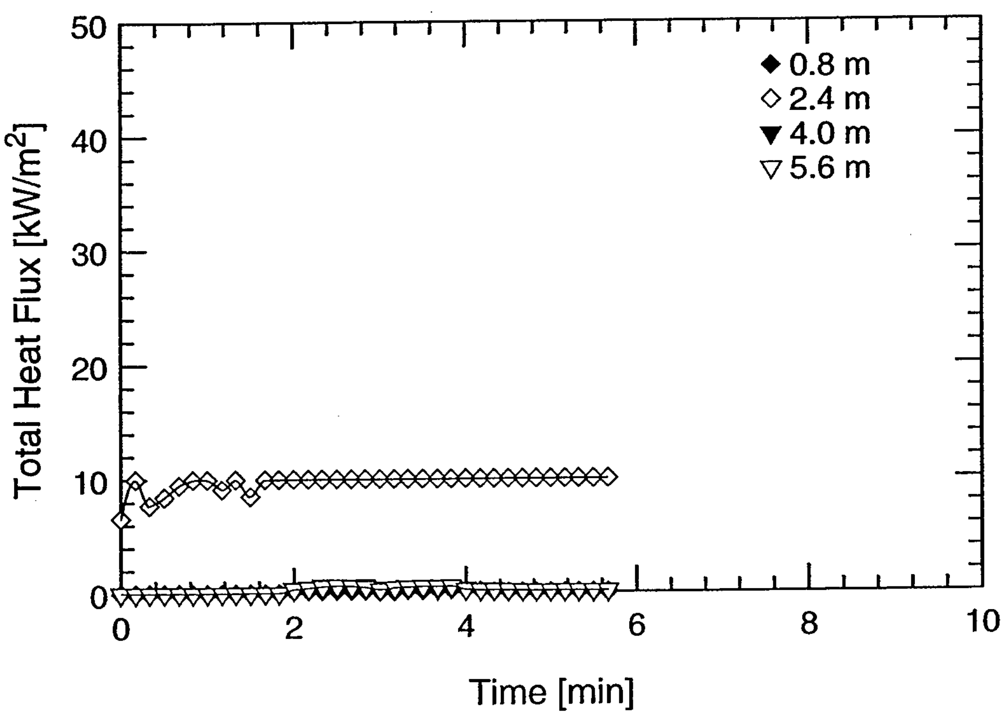


FR 36 - 4.5 m

Test #32

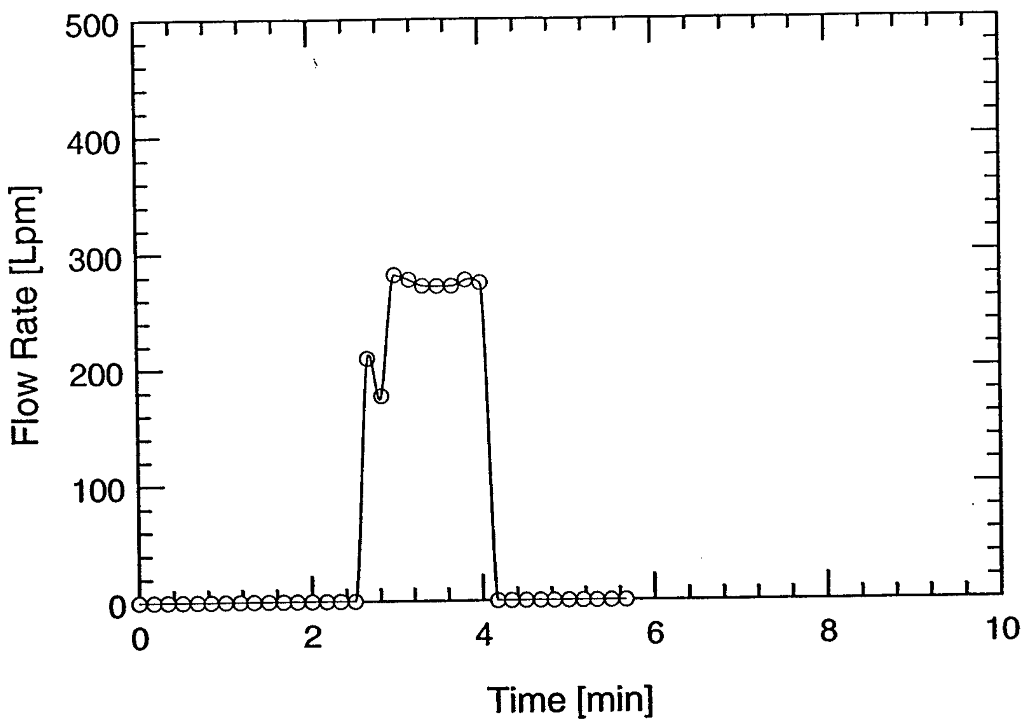


FR 22

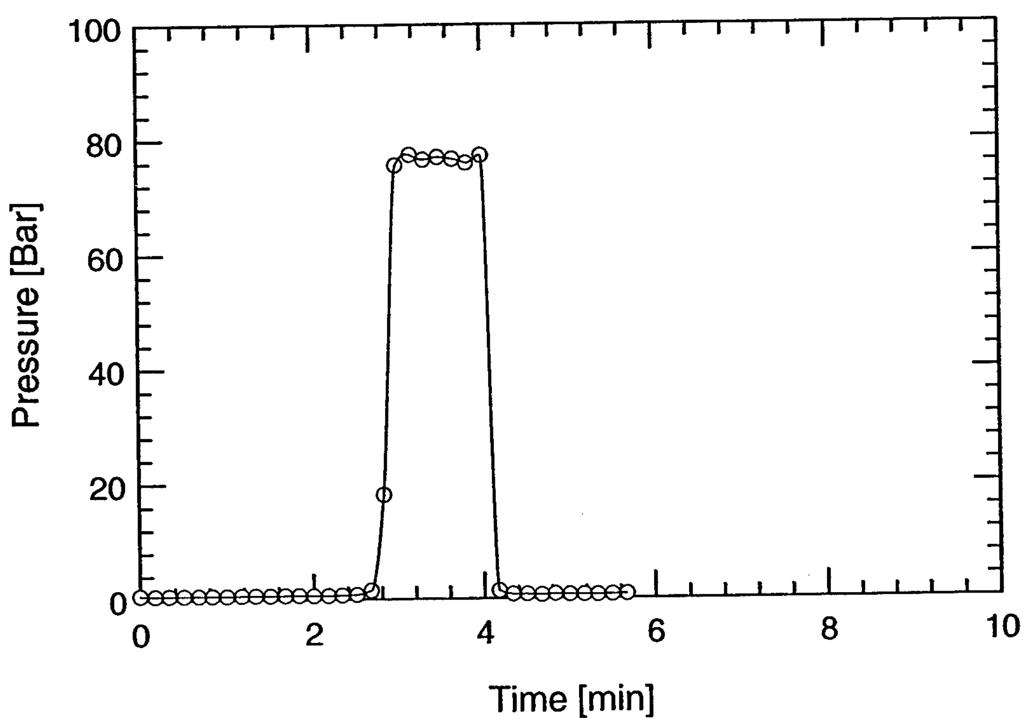


FR 22

Test #32

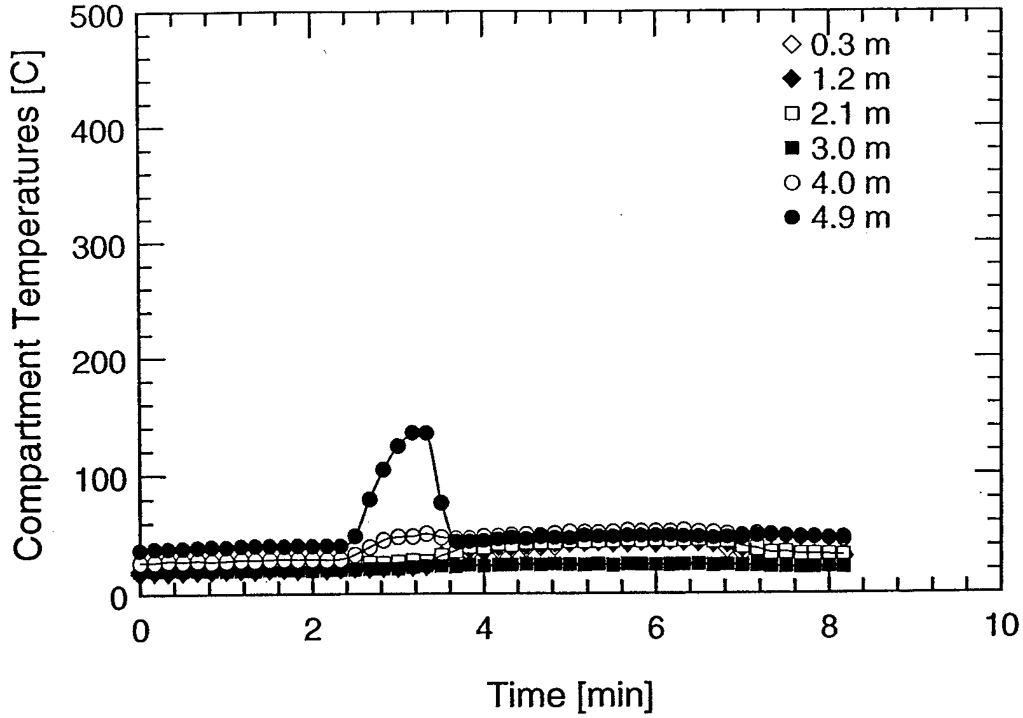


Water Mist System Flow Rate

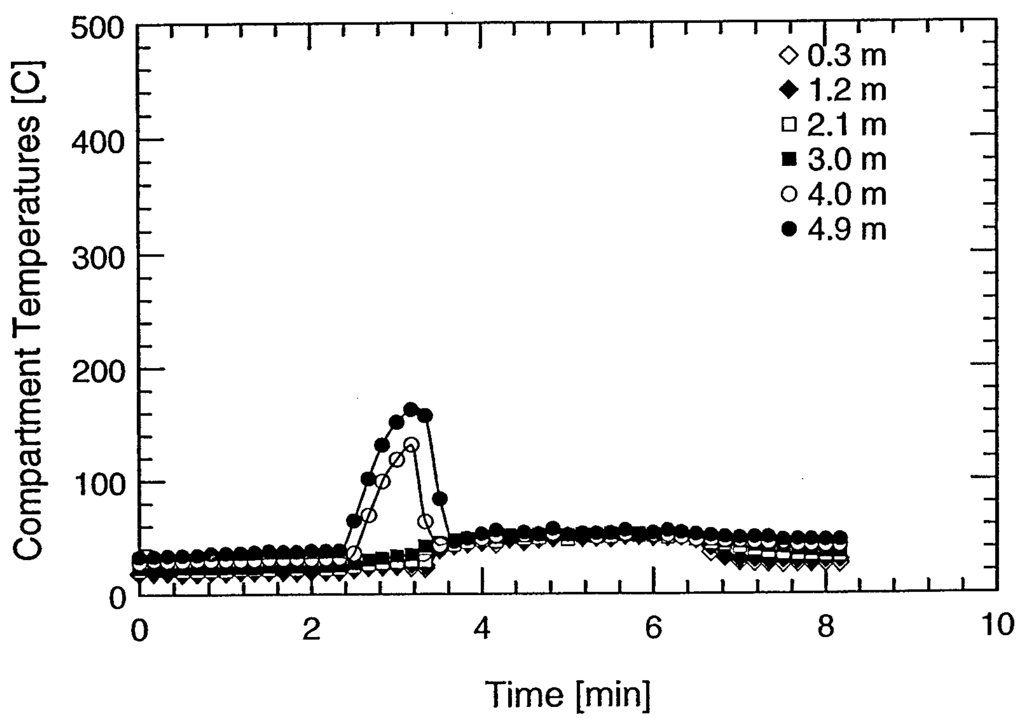


Water Mist System Pressure

Test #32

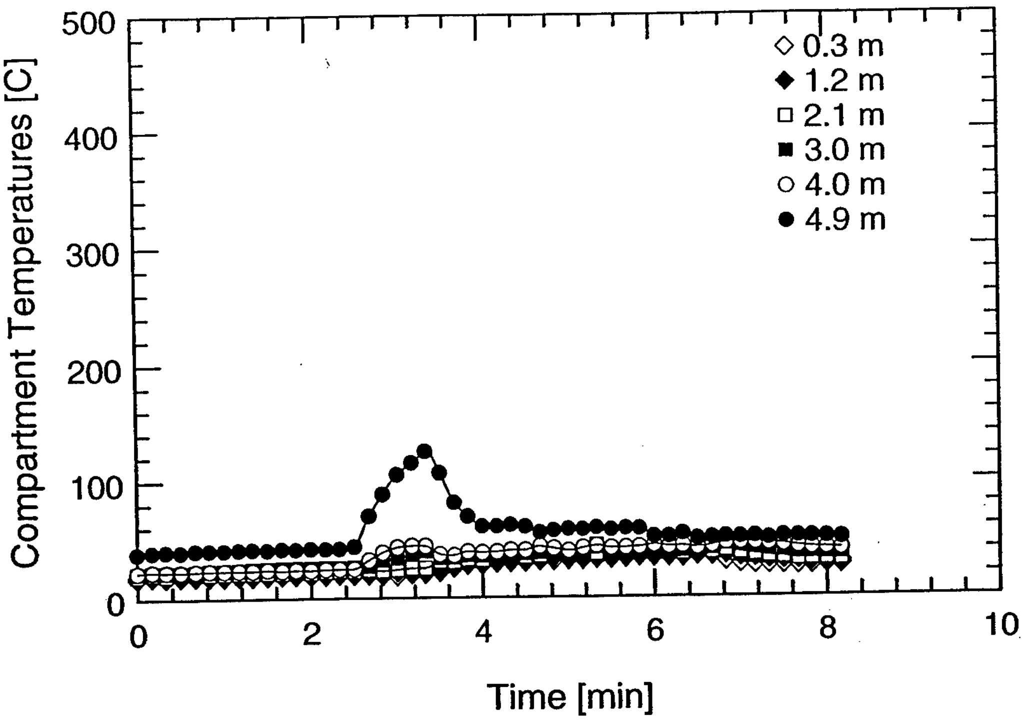


5-22-1

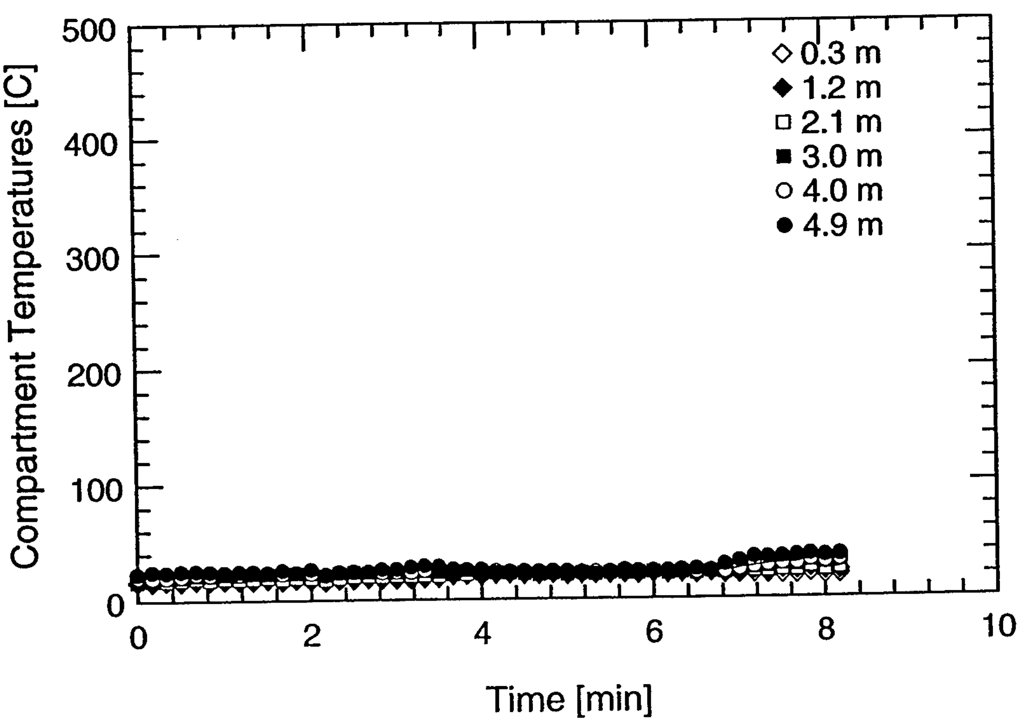


5-27-1

Test #33

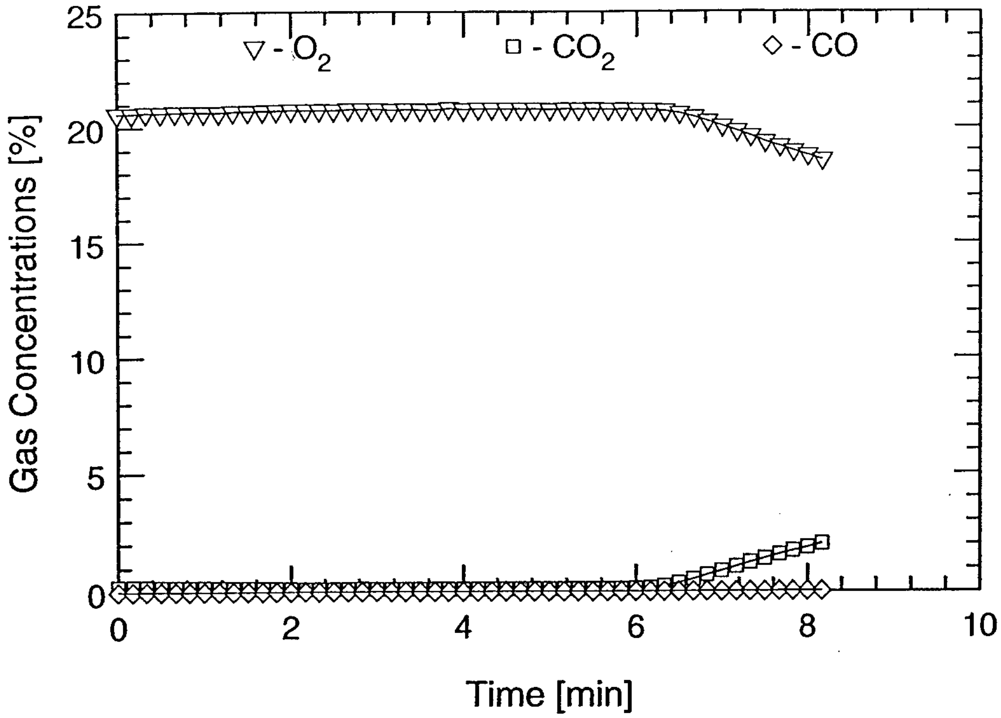


5-27-2

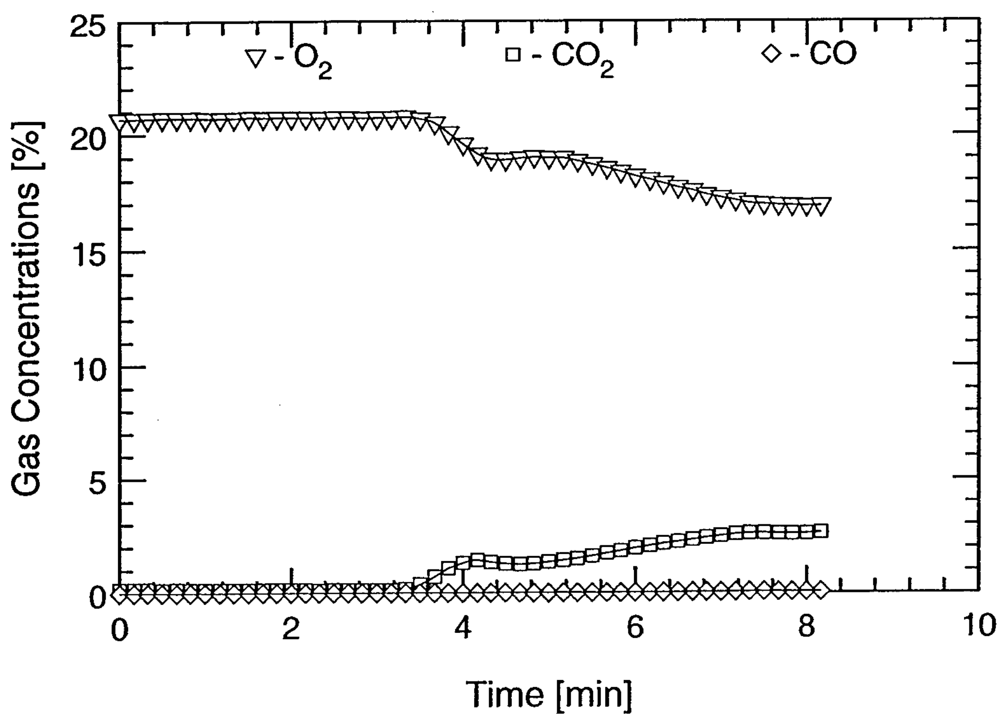


5-35-1

Test #33

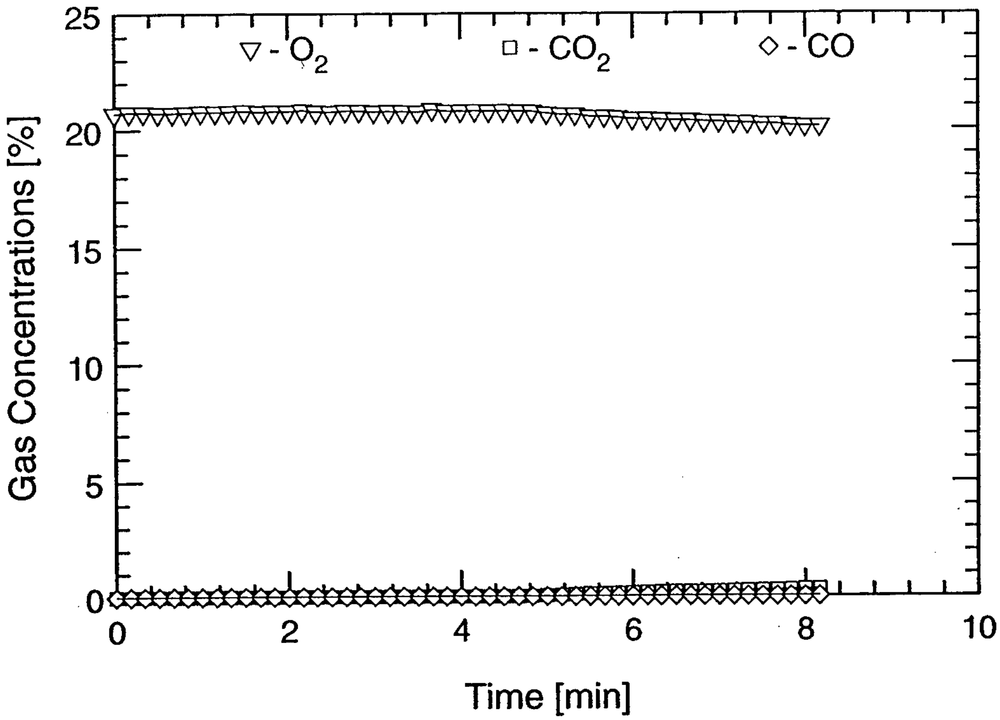


FR 22 - 0.5 m

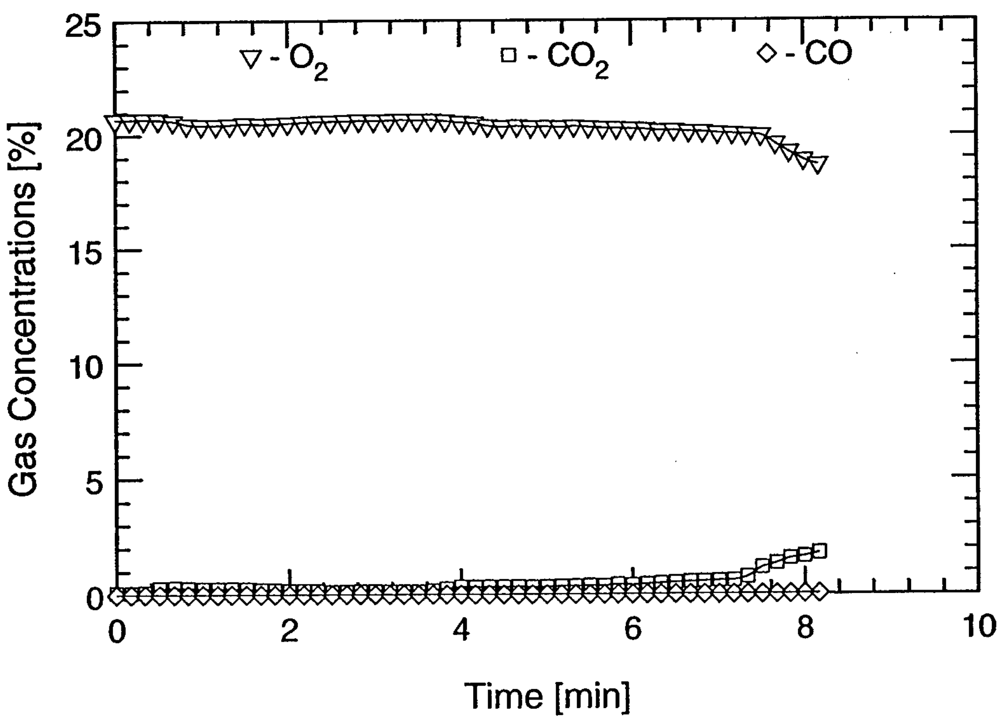


FR 22 - 4.5 m

Test #33

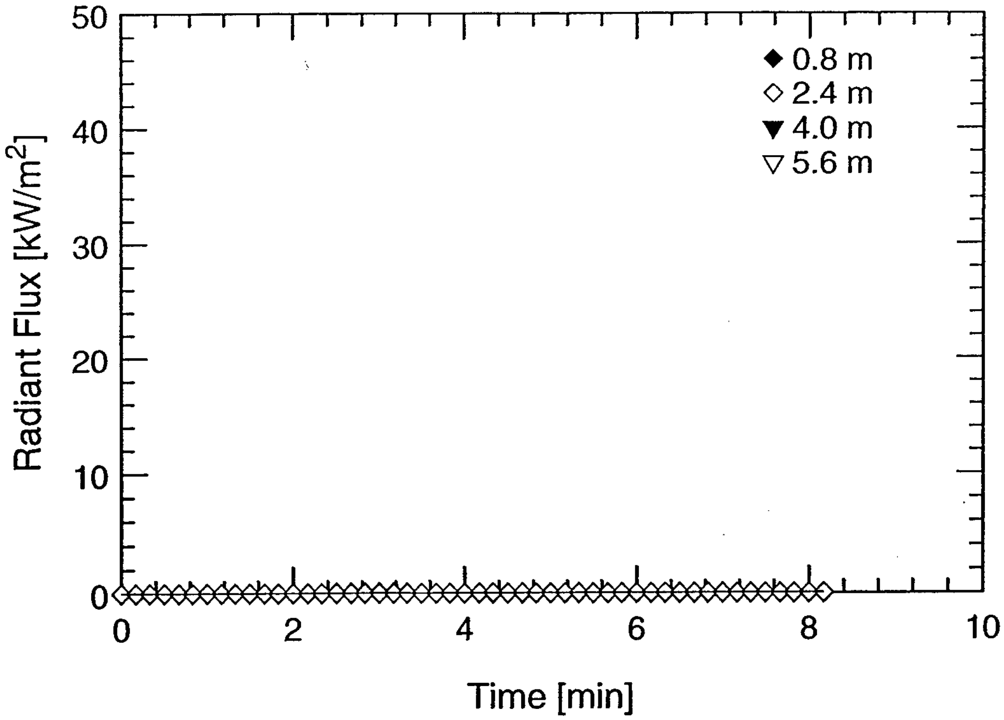


FR 36 - 0.5 m

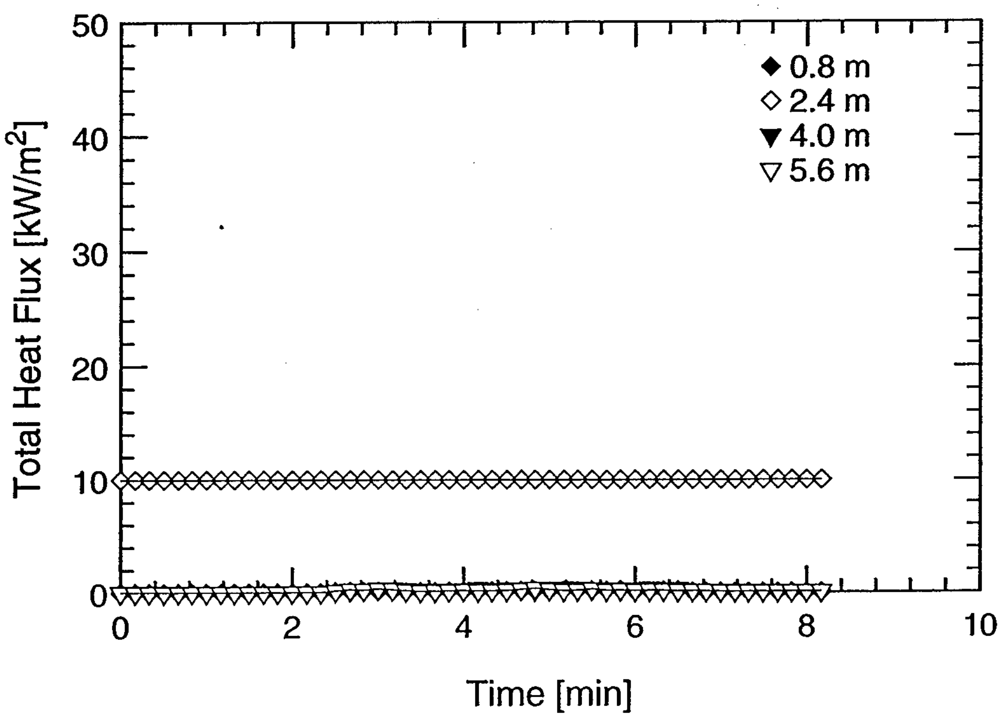


FR 36 - 4.5 m

Test #33

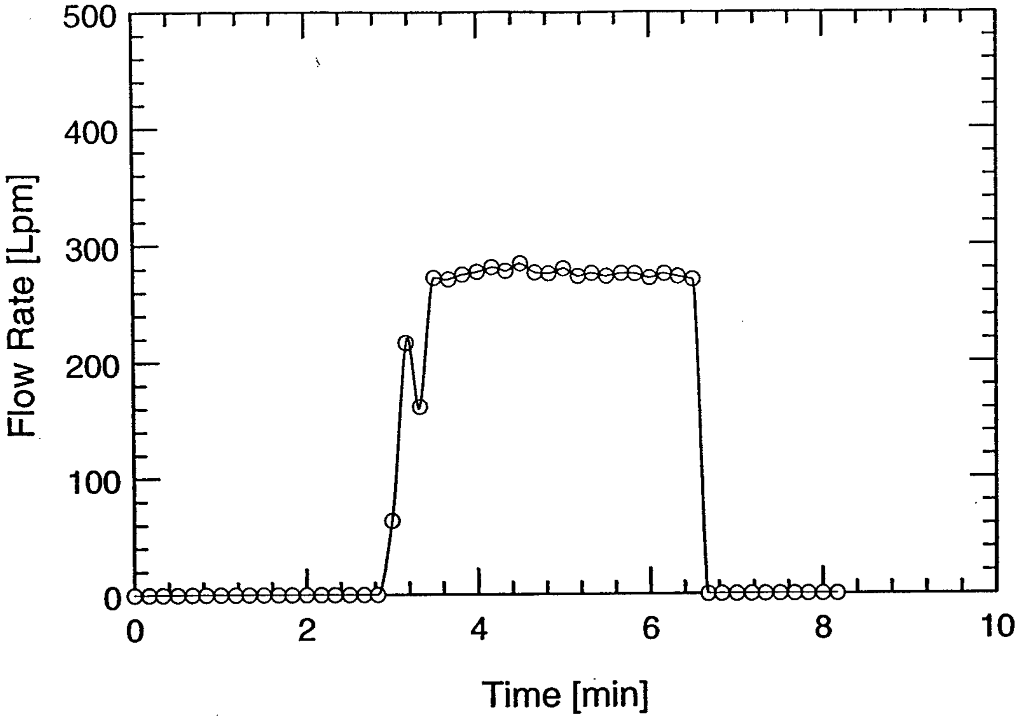


FR 22

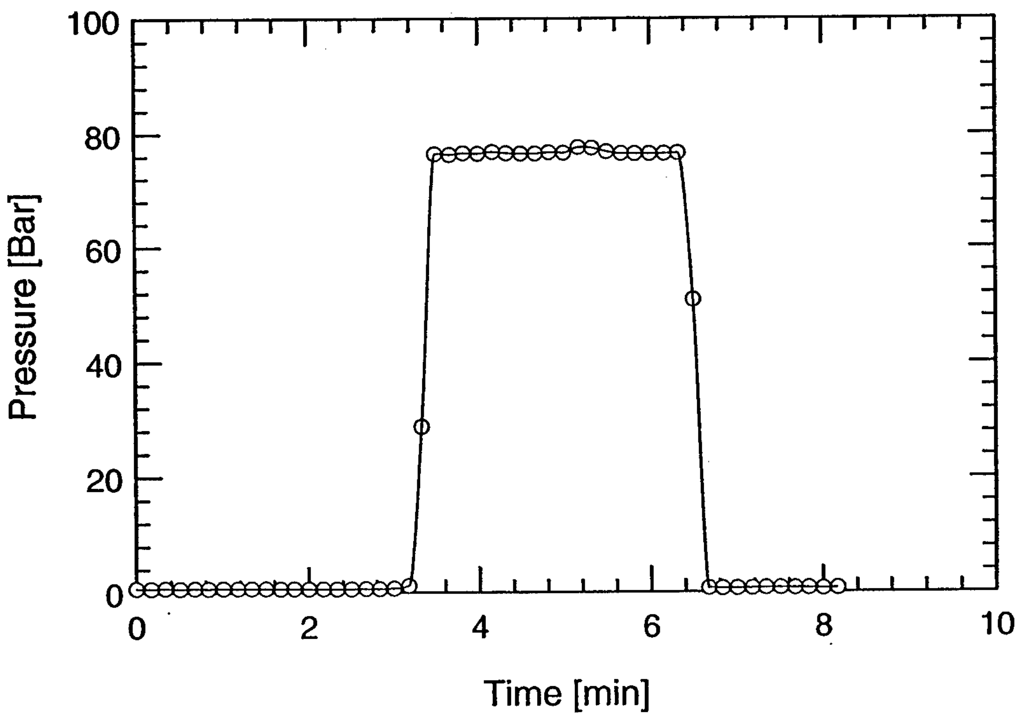


FR 22

Test #33

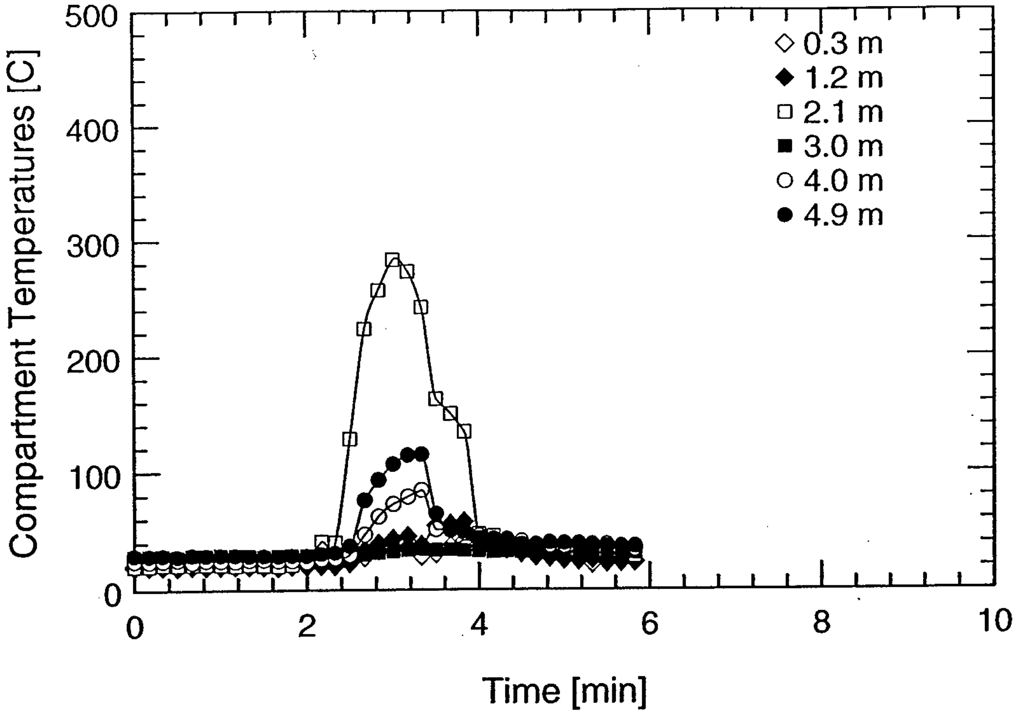


Water Mist System Flow Rate

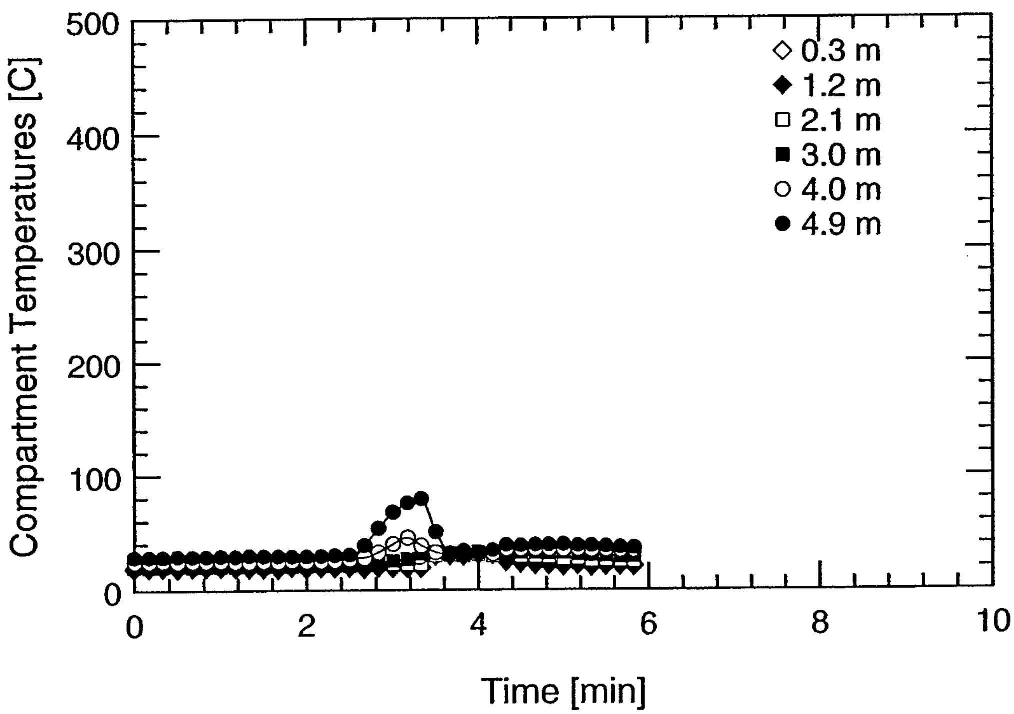


Water Mist System Pressure

Test #33

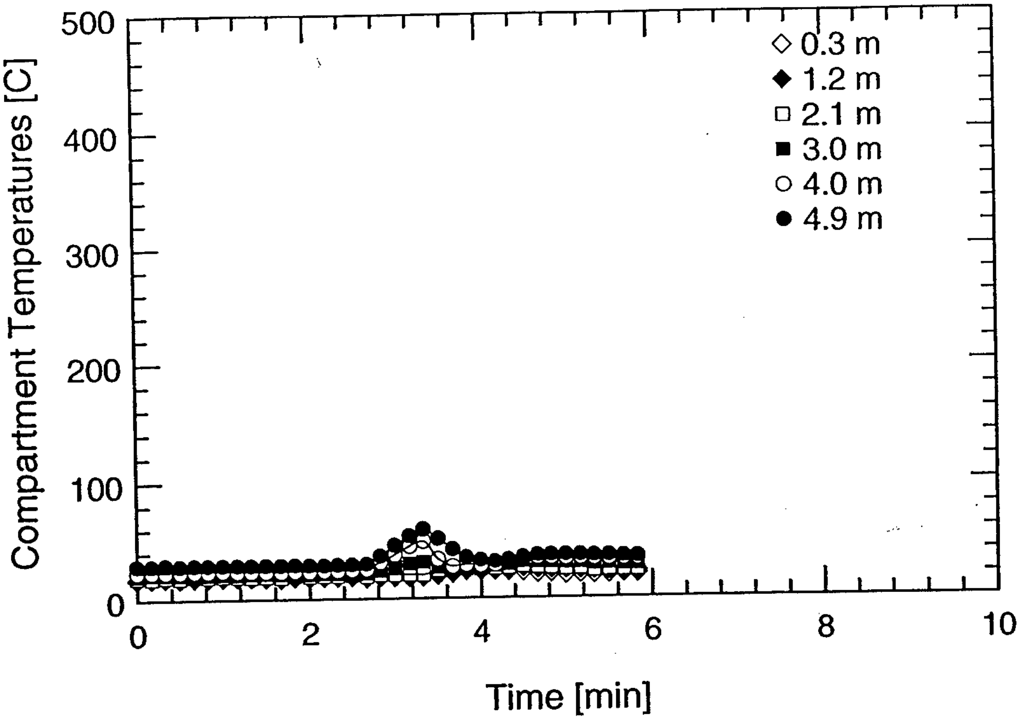


5-22-1

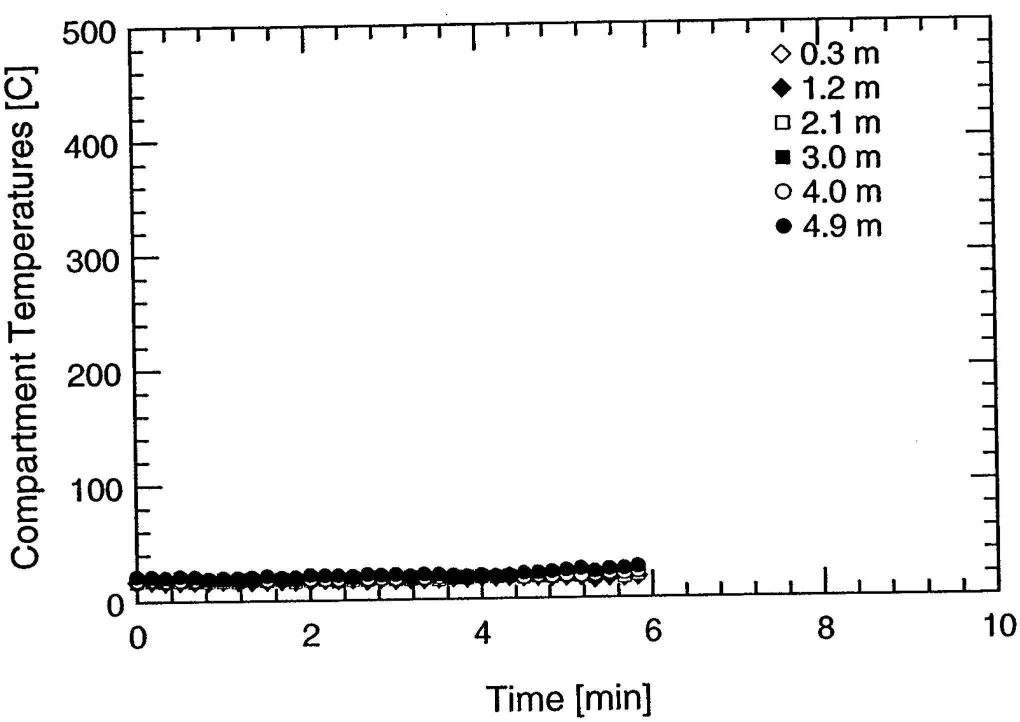


5-27-1

Test #34

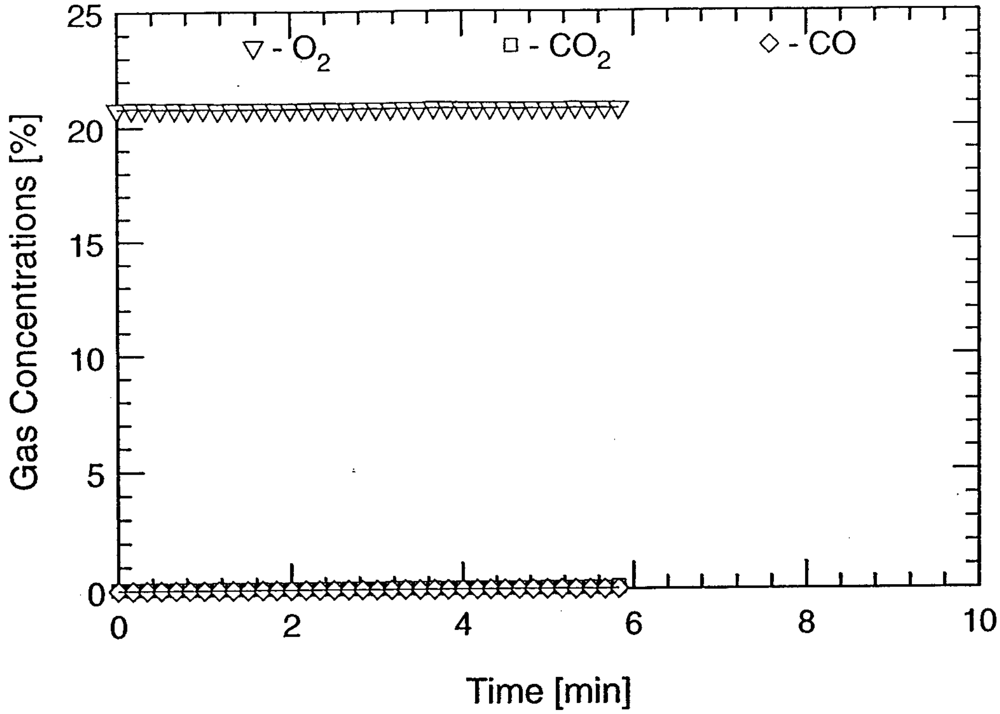


5-27-2

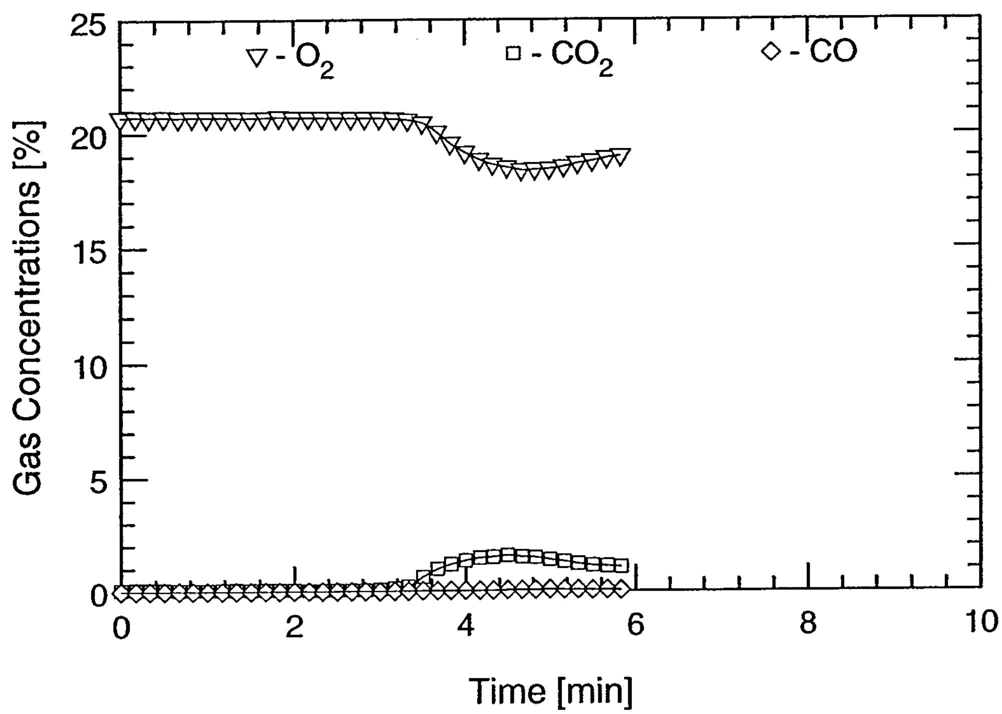


5-35-1

Test #34

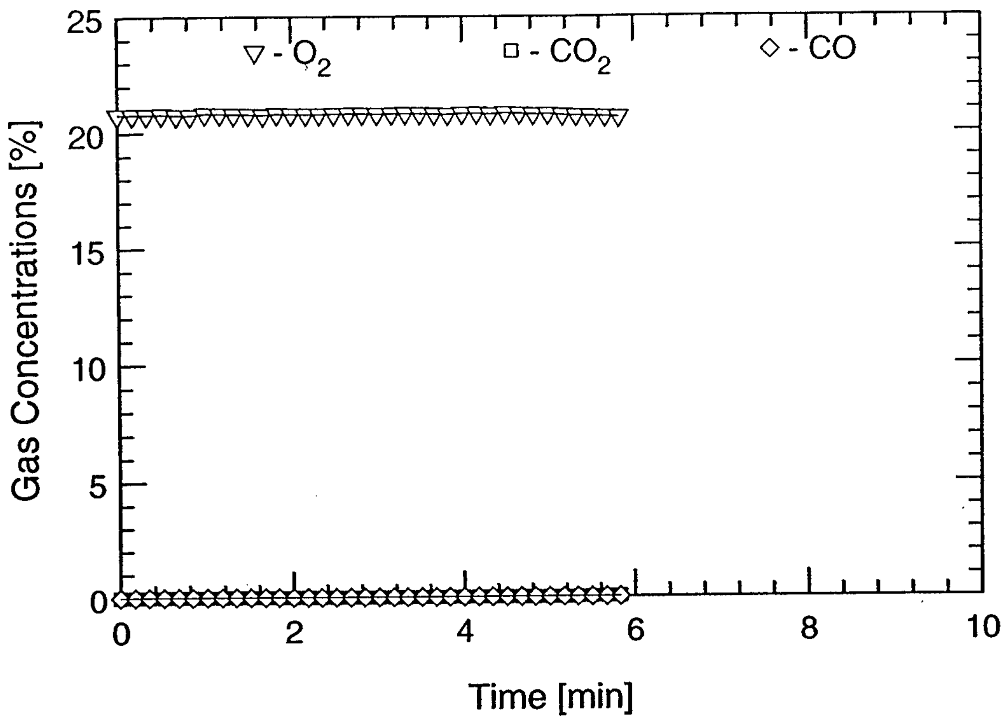


FR 22 - 0.5 m

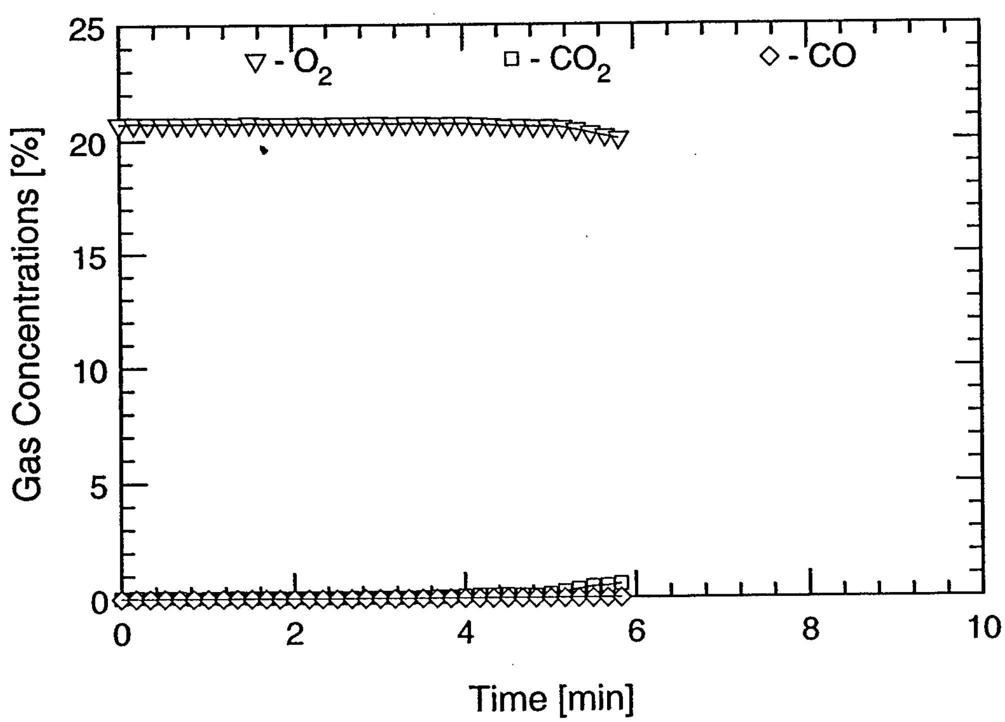


FR 22 - 4.5 m

Test #34

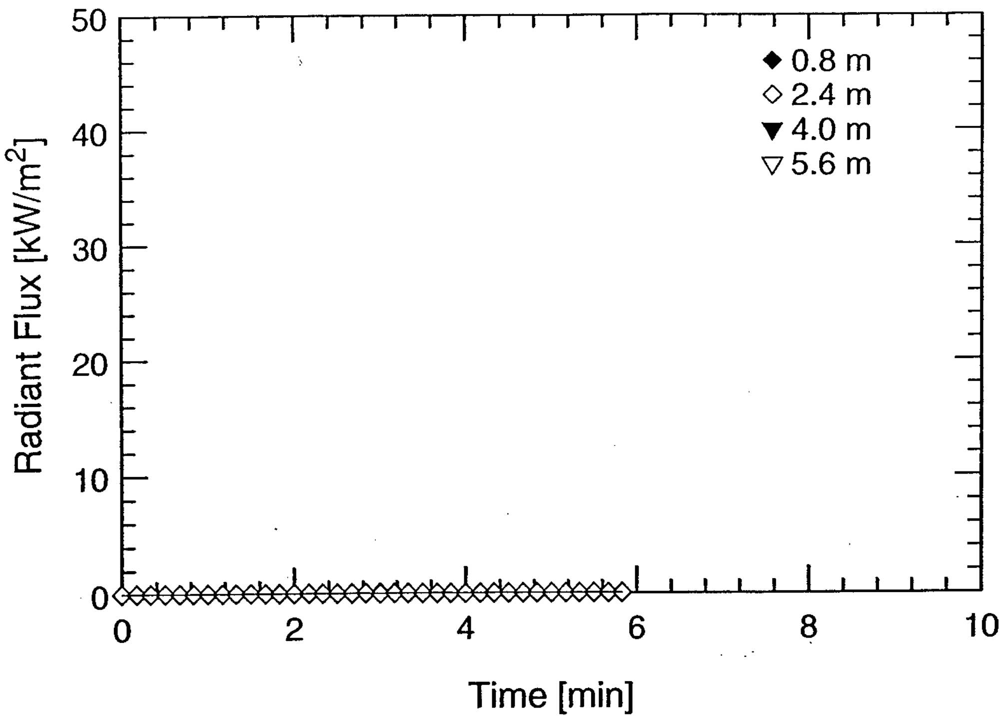


FR 36 - 0.5 m

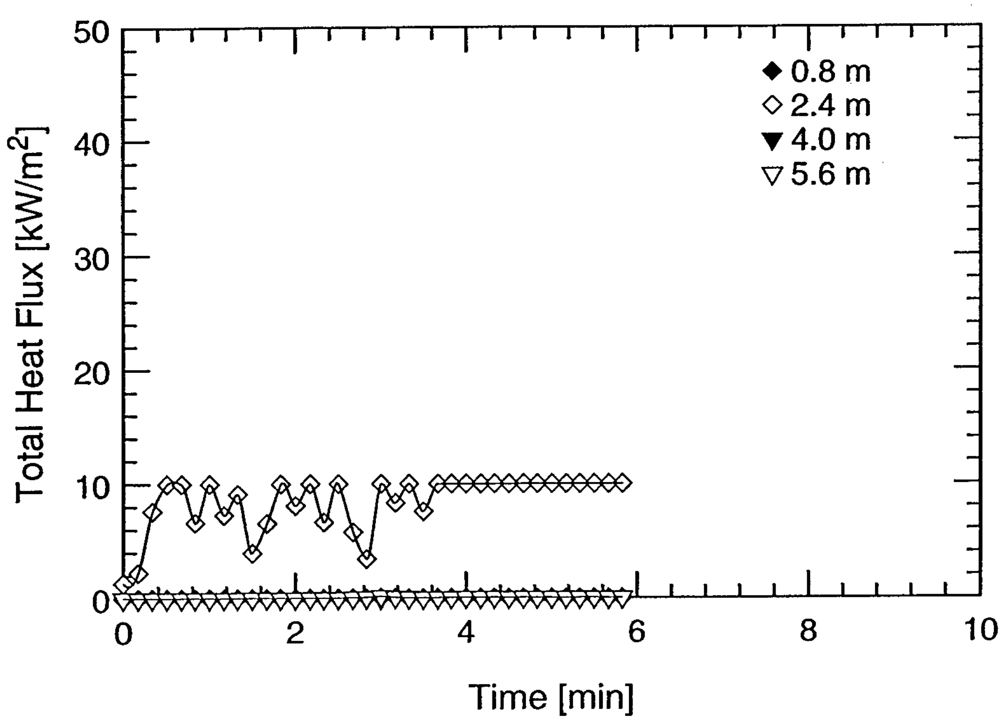


FR 36 - 4.5 m

Test #34

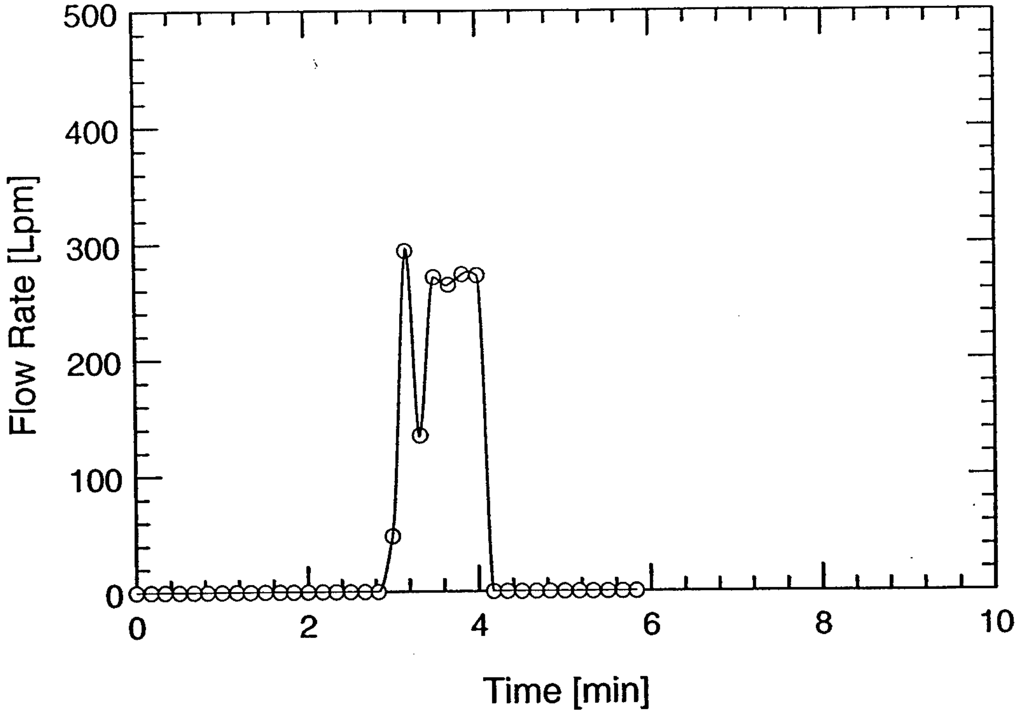


FR 22

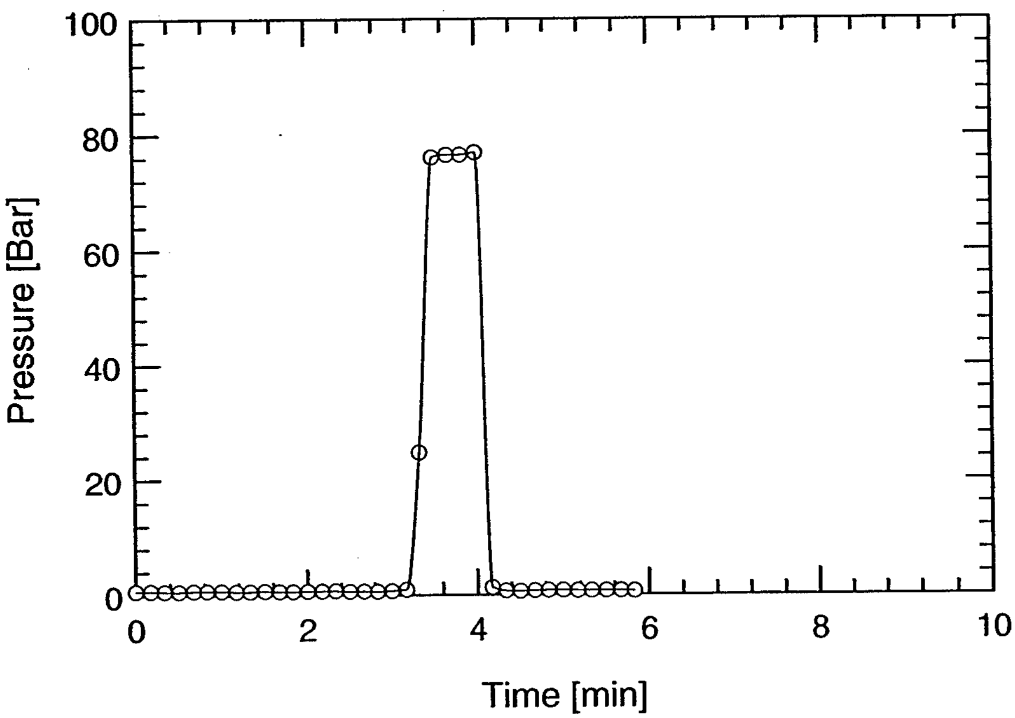


FR 22

Test #34

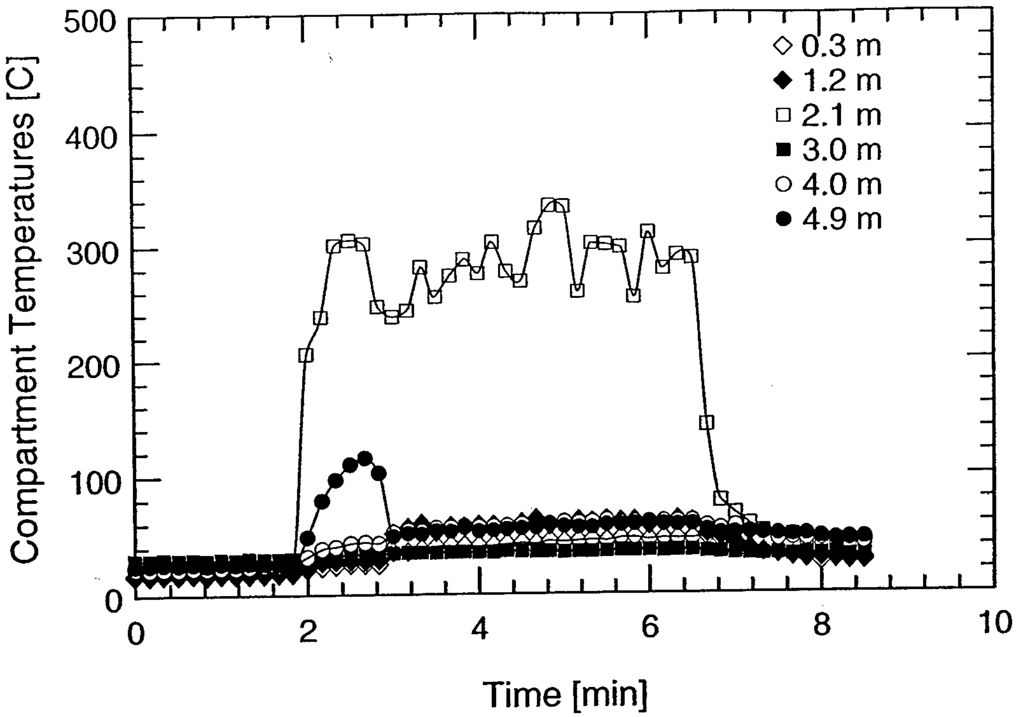


Water Mist System Flow Rate

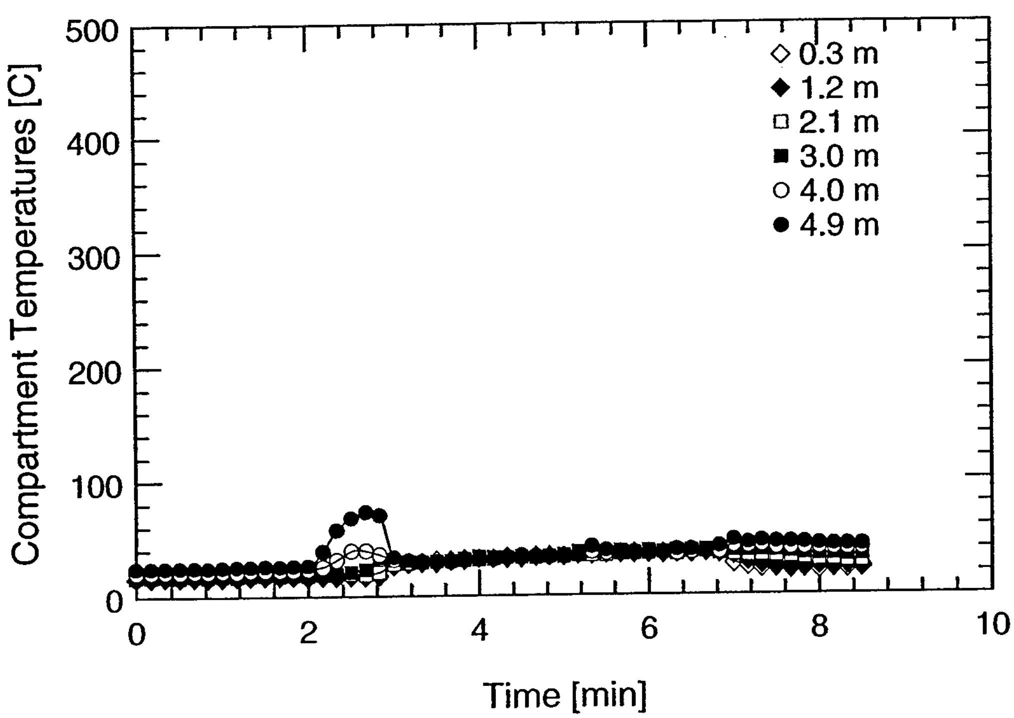


Water Mist System Pressure

Test #34

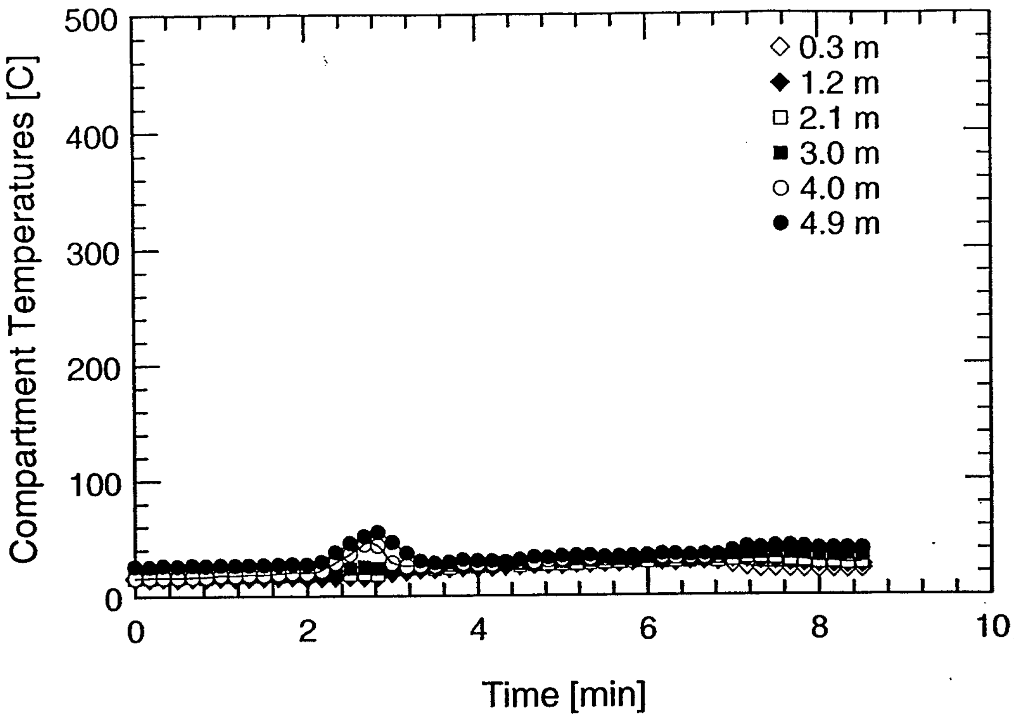


5-22-1

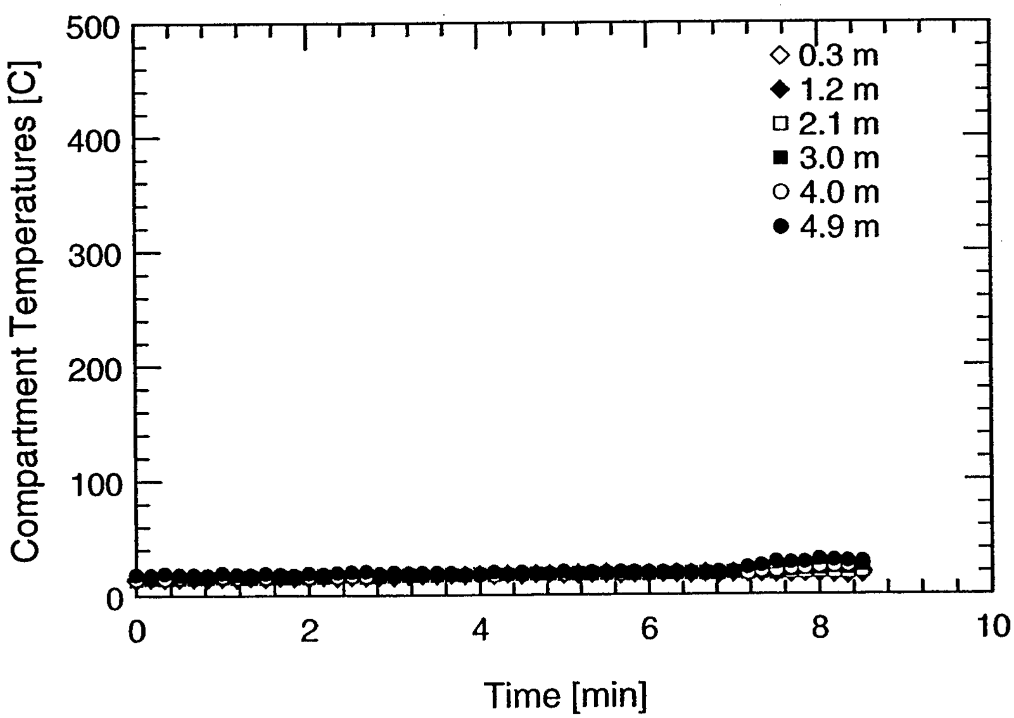


5-27-1

Test #35

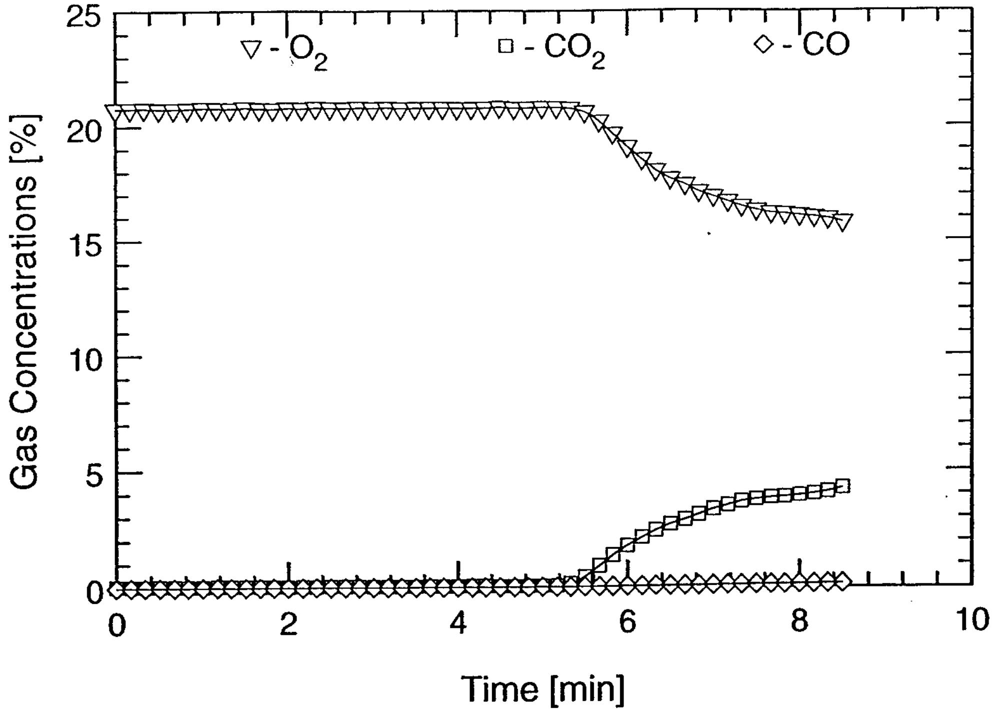


5-27-2

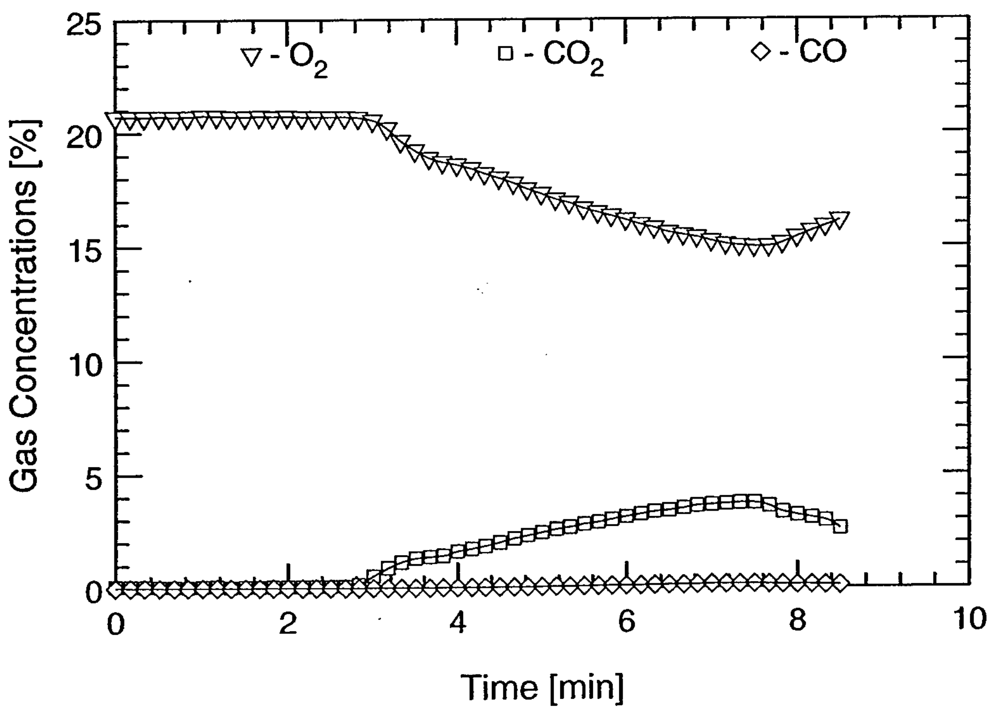


5-35-1

Test #35

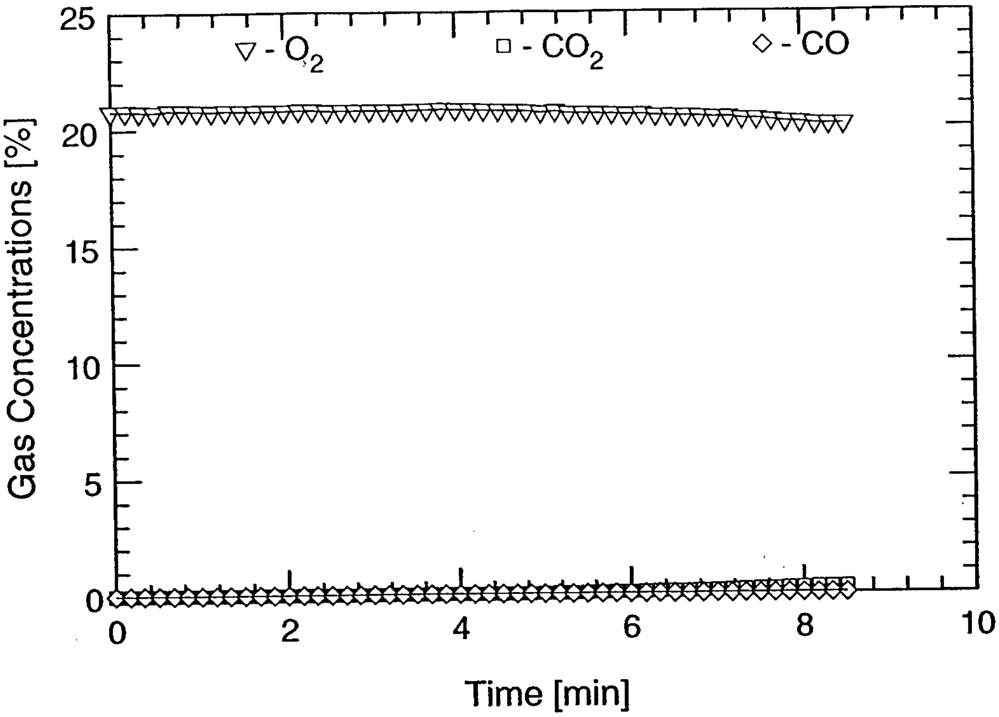


FR 22 - 0.5 m

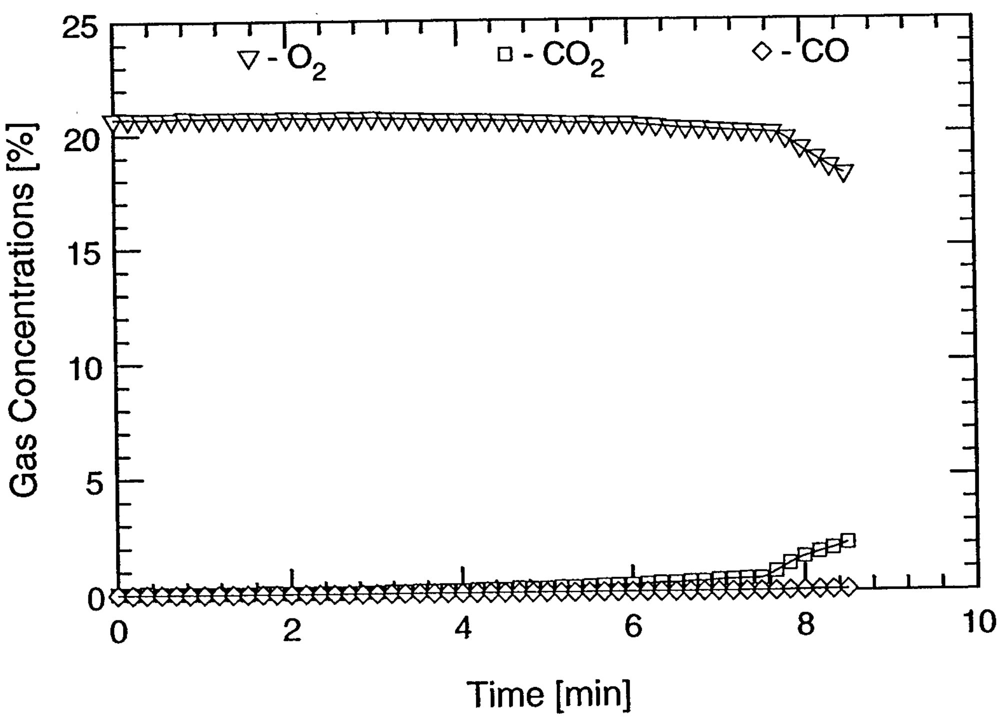


FR 22 - 4.5 m

Test #35

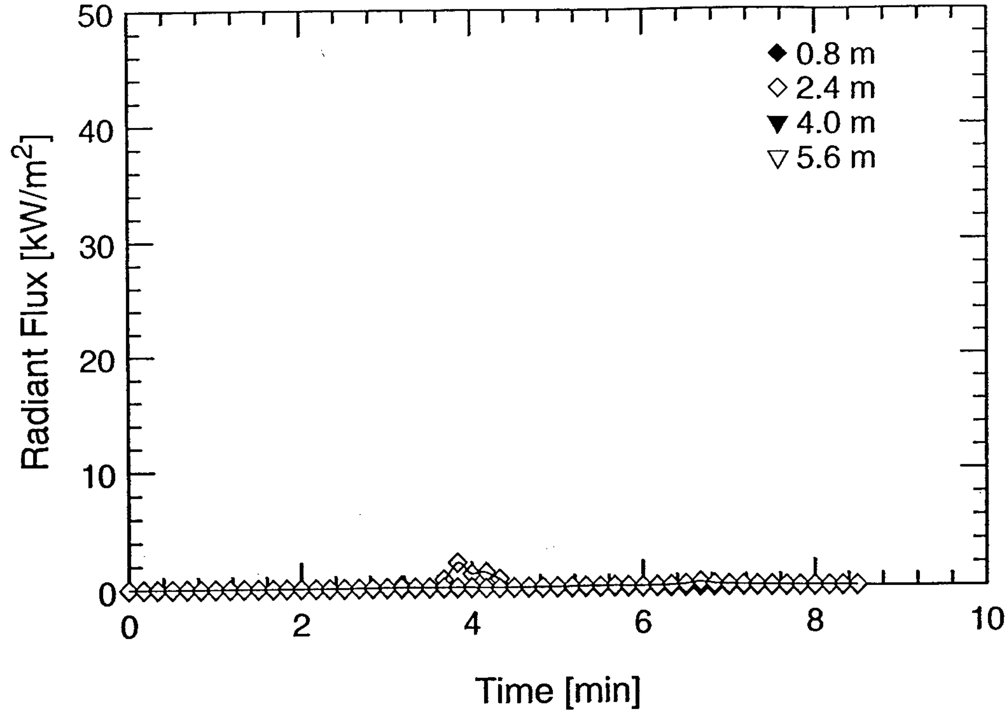


FR 36 - 0.5 m

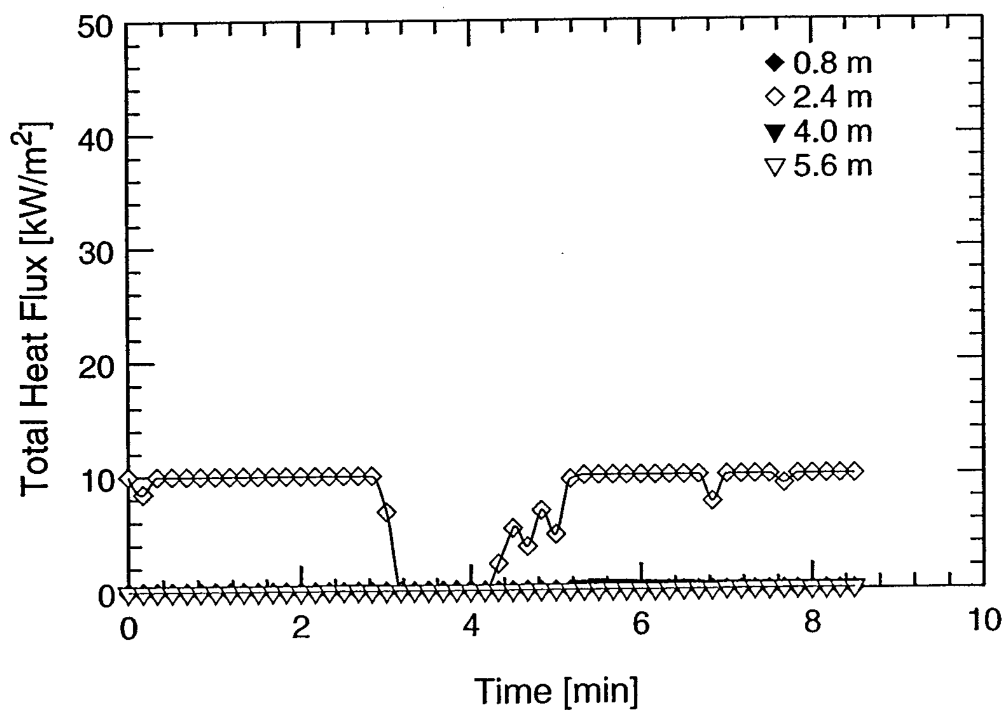


FR 36 - 4.5 m

Test #35

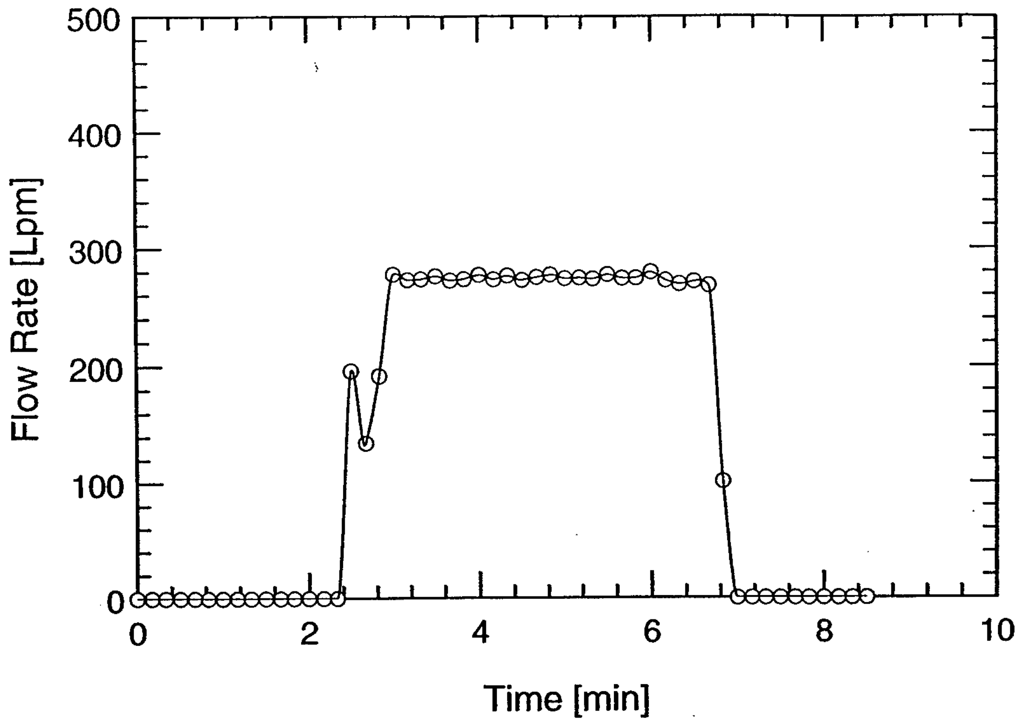


FR 22

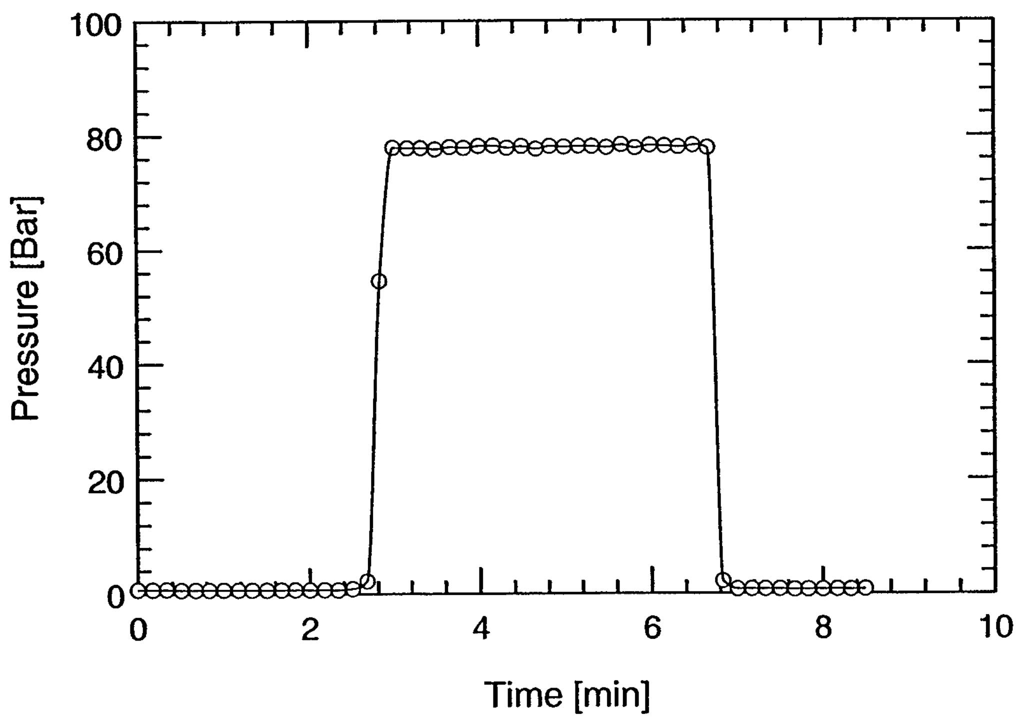


FR 22

Test #35

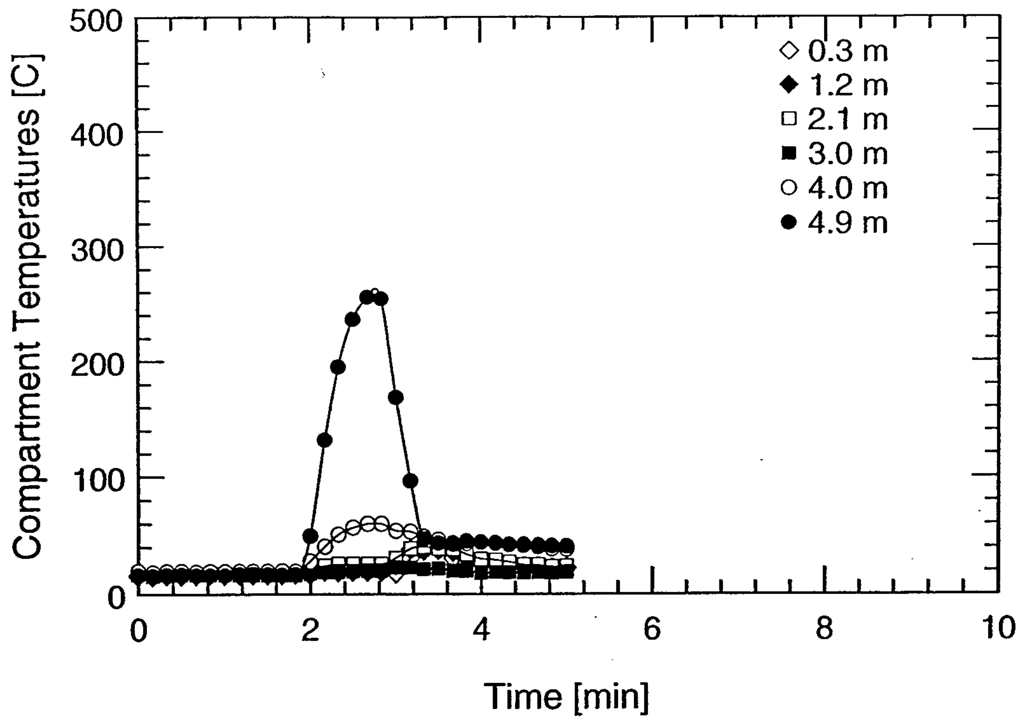


Water Mist System Flow Rate

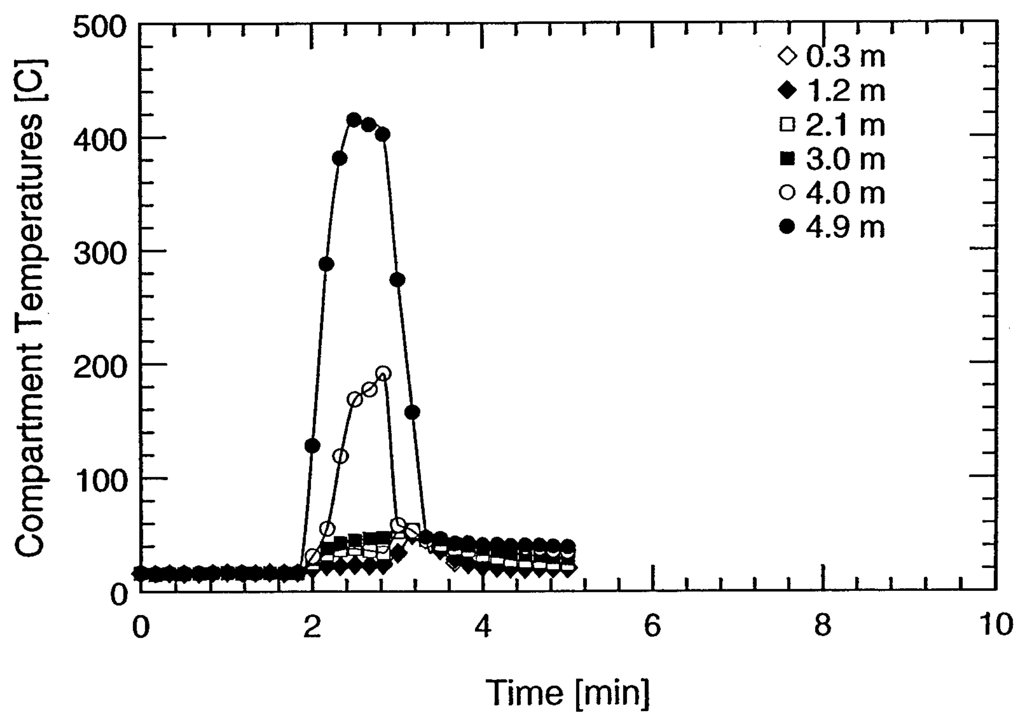


Water Mist System Pressure

Test #35

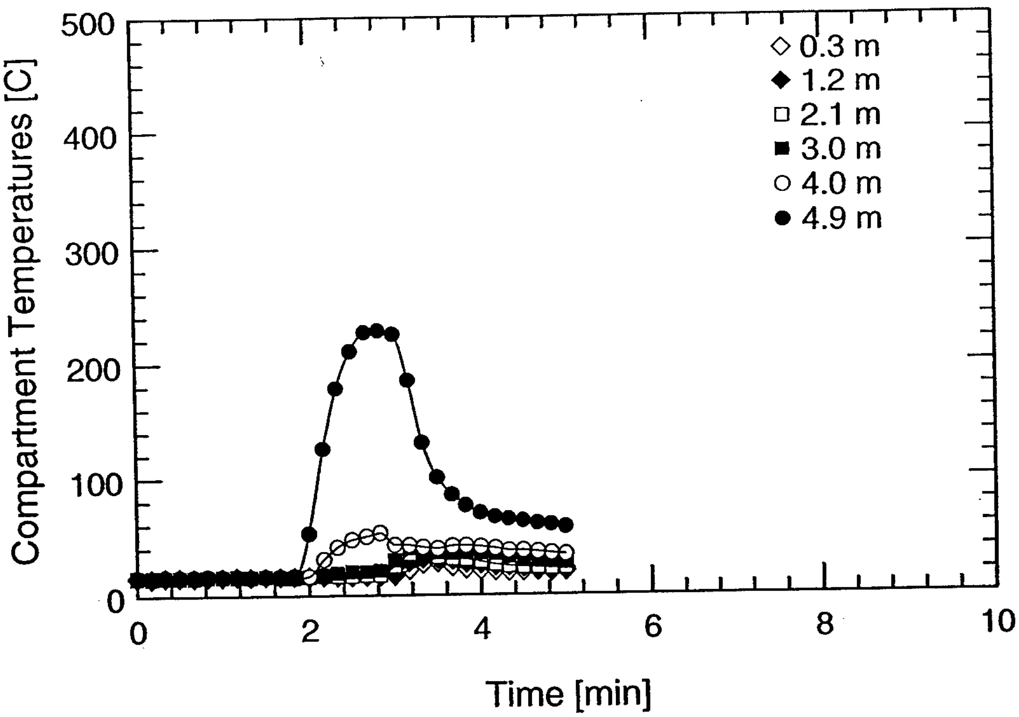


5-22-1

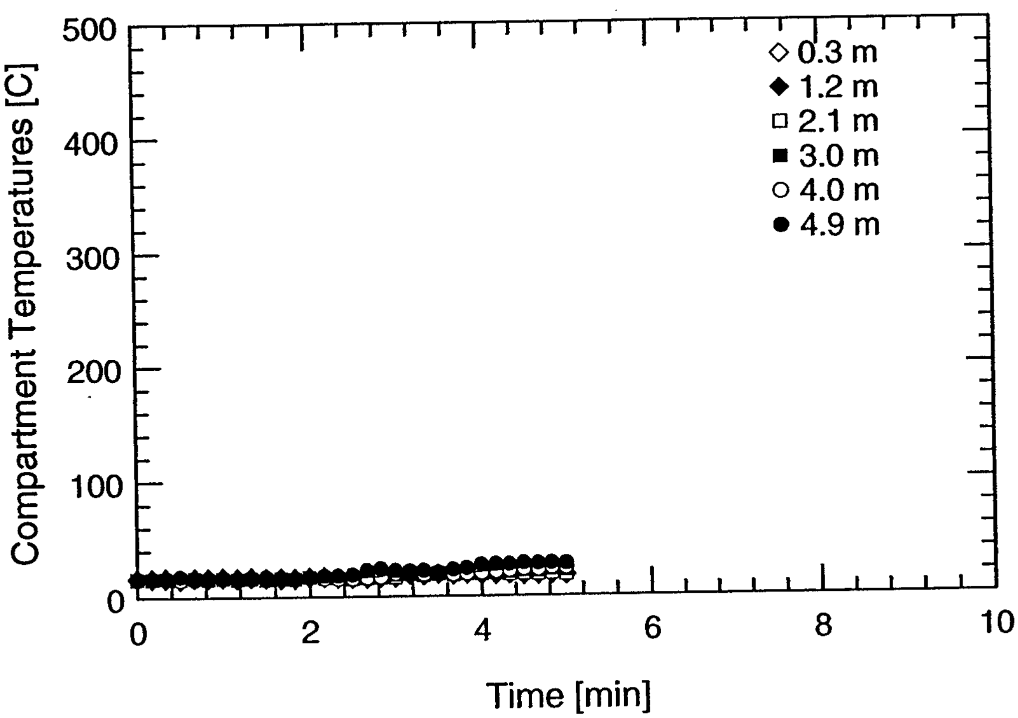


5-27-1

Test #36

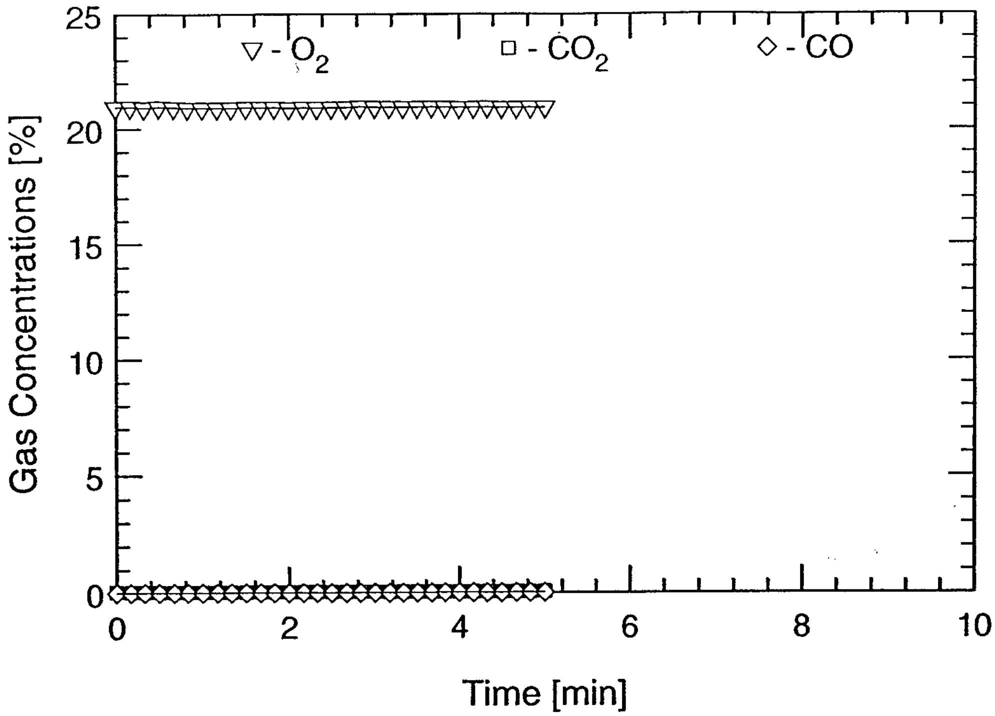


5-27-2

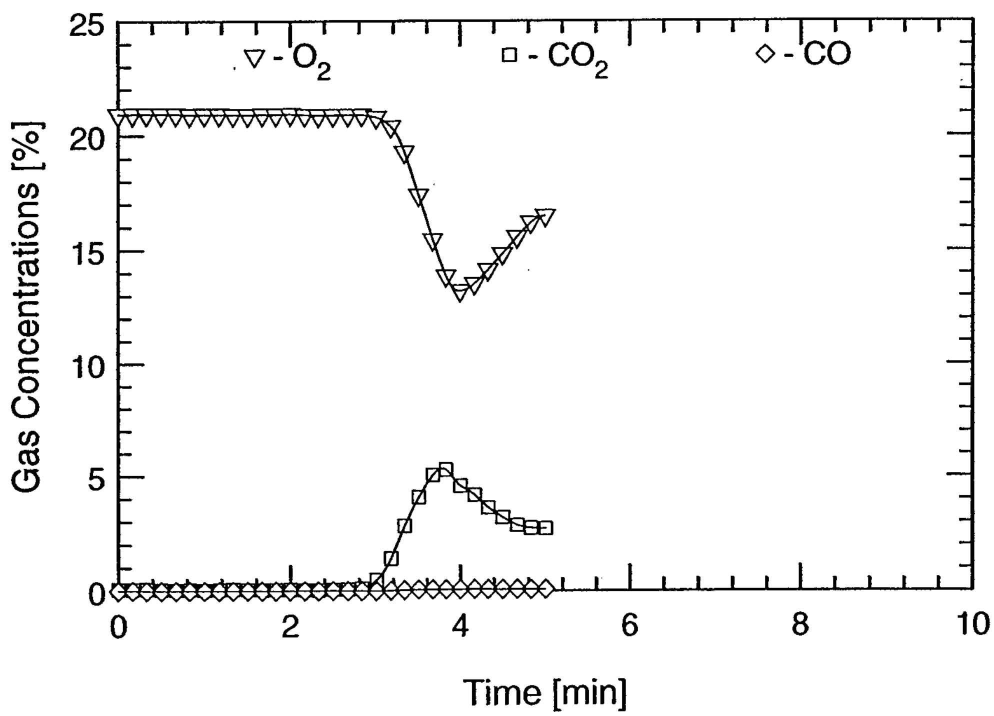


5-35-1

Test #36

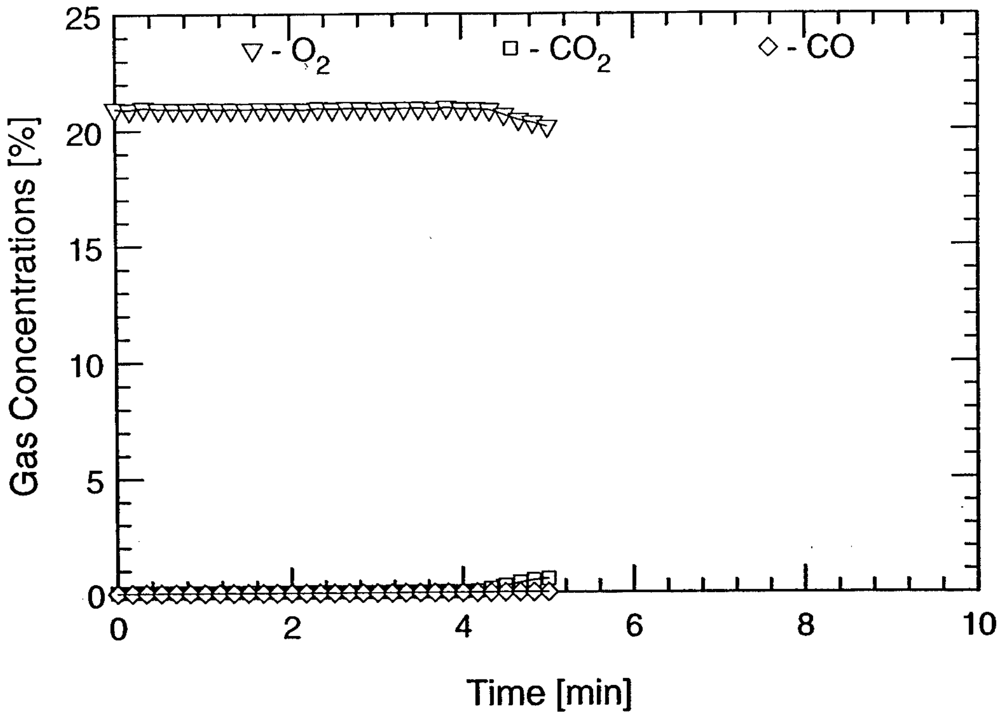


FR 22 - 0.5 m

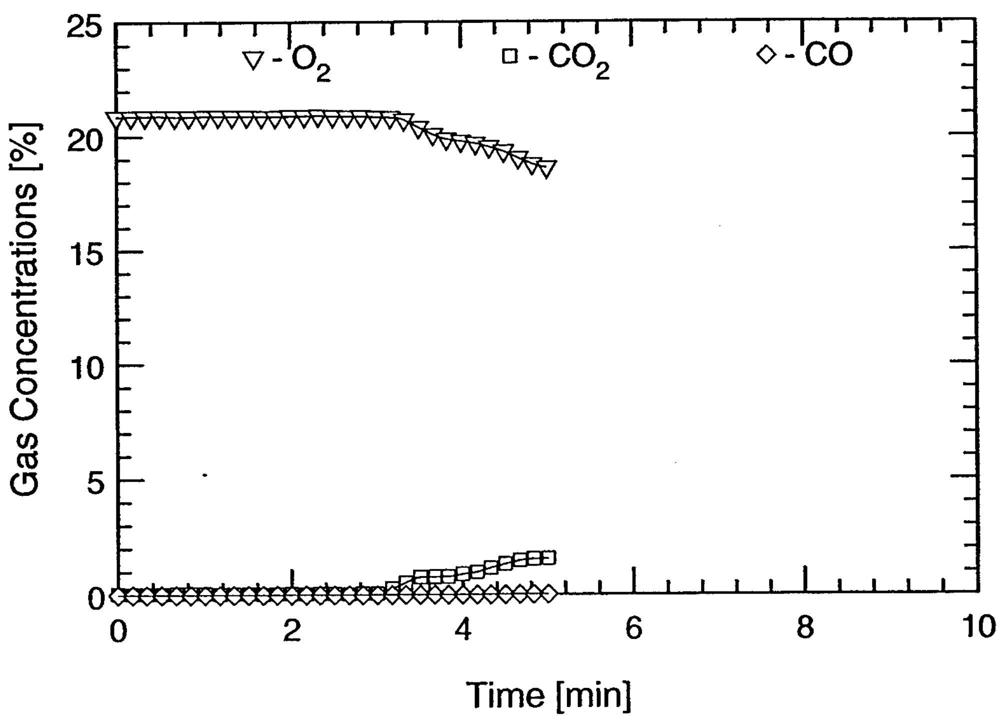


FR 22 - 4.5 m

Test #36

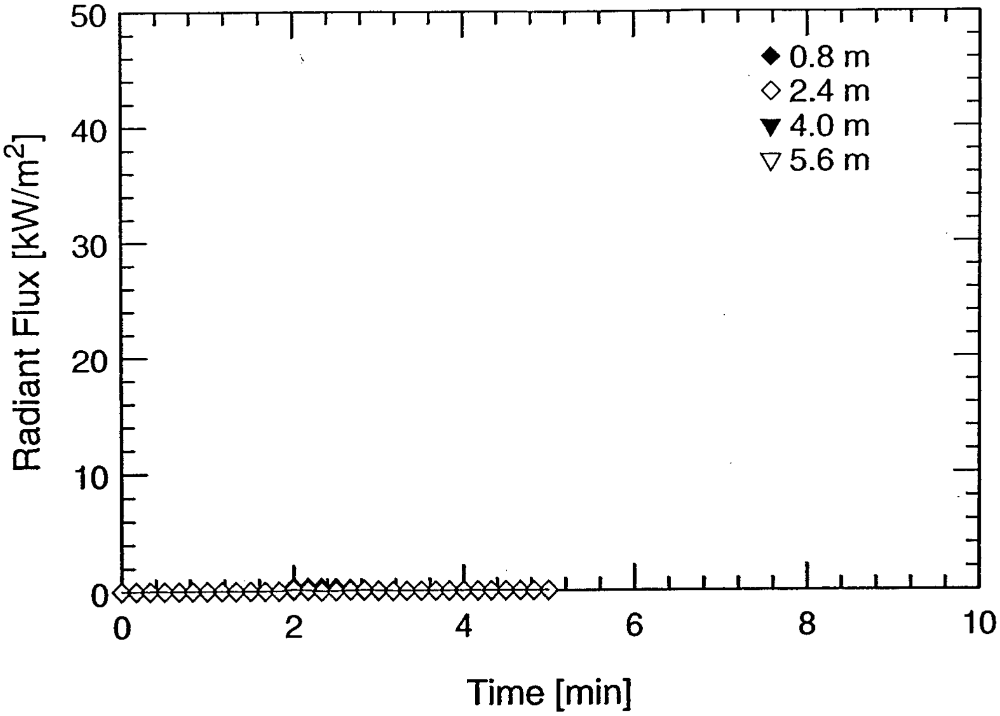


FR 36 - 0.5 m

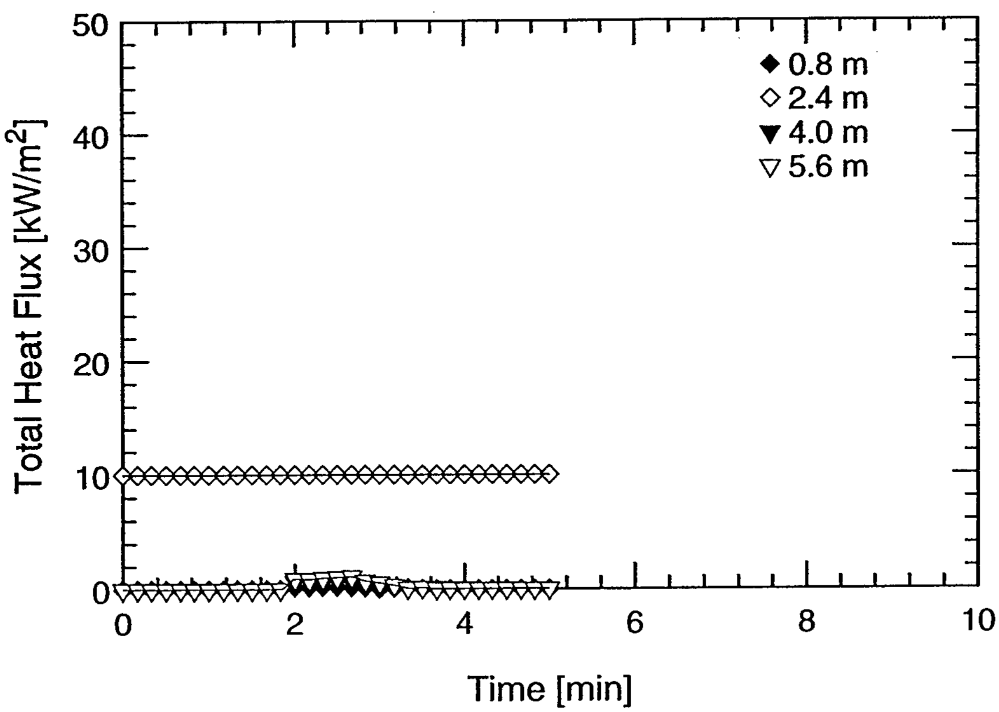


FR 36 - 4.5 m

Test #36

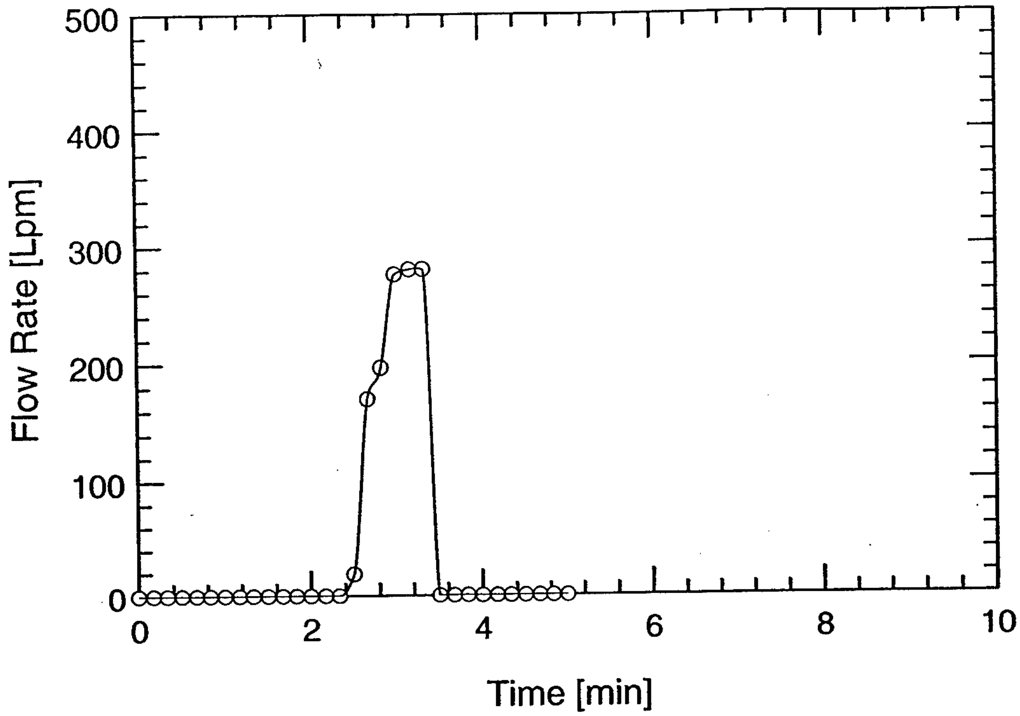


FR 22

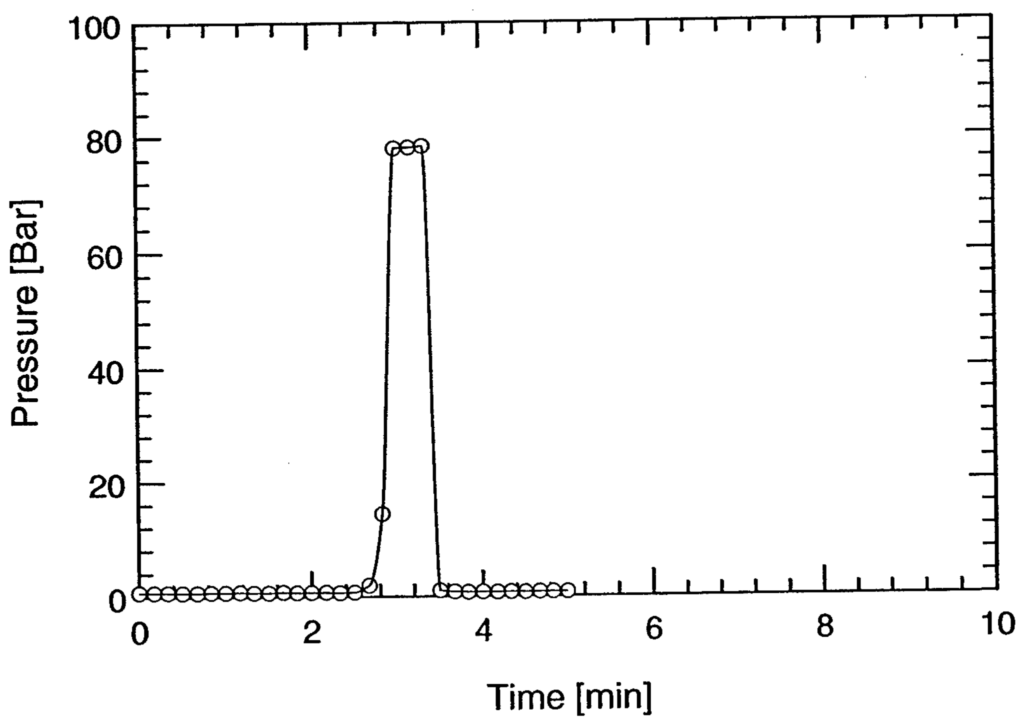


FR 22

Test #36

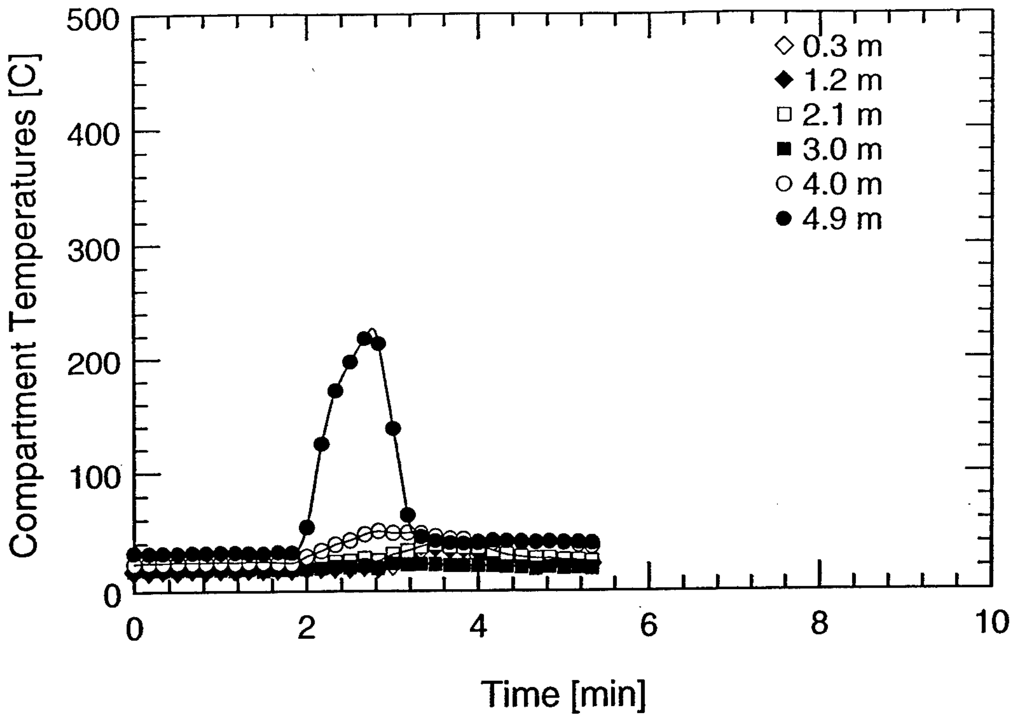


Water Mist System Flow Rate

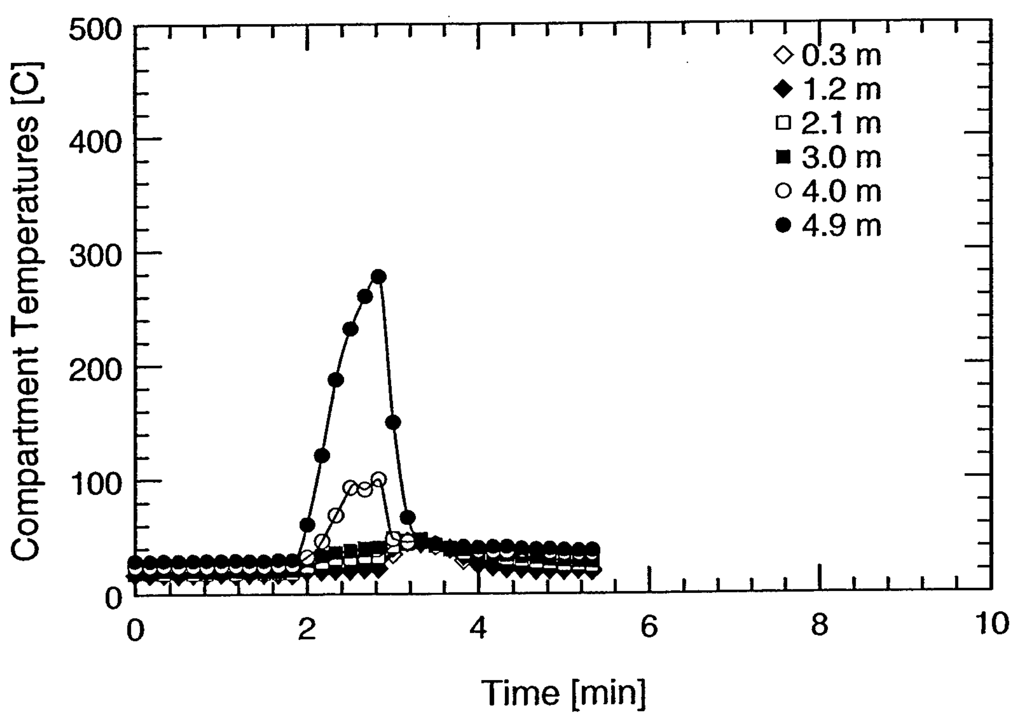


Water Mist System Pressure

Test #36

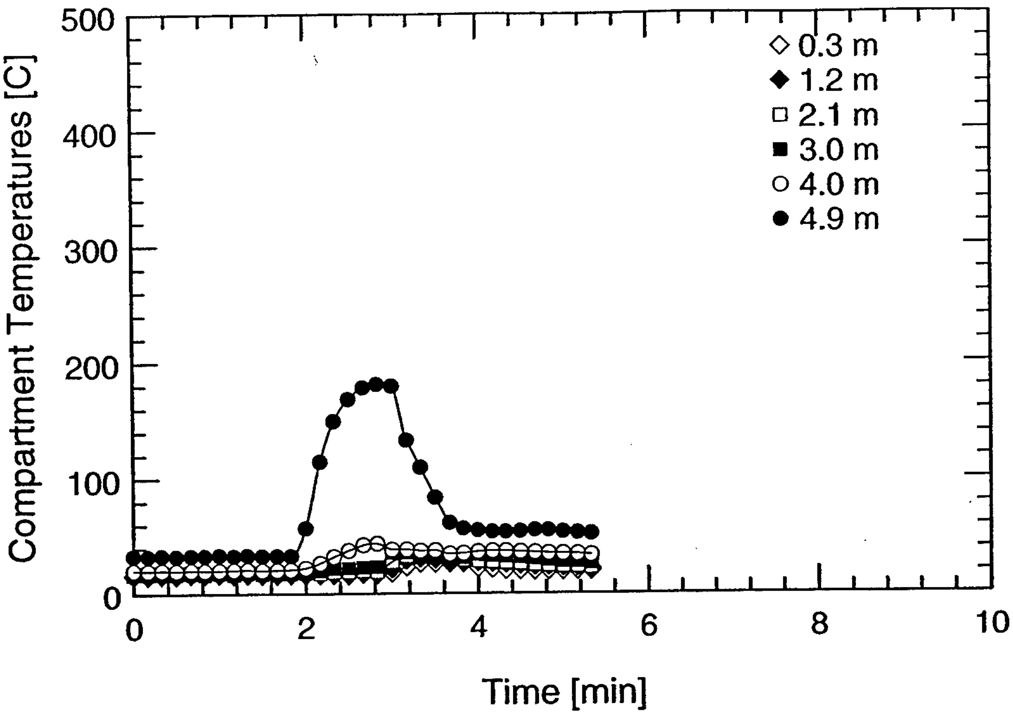


5-22-1

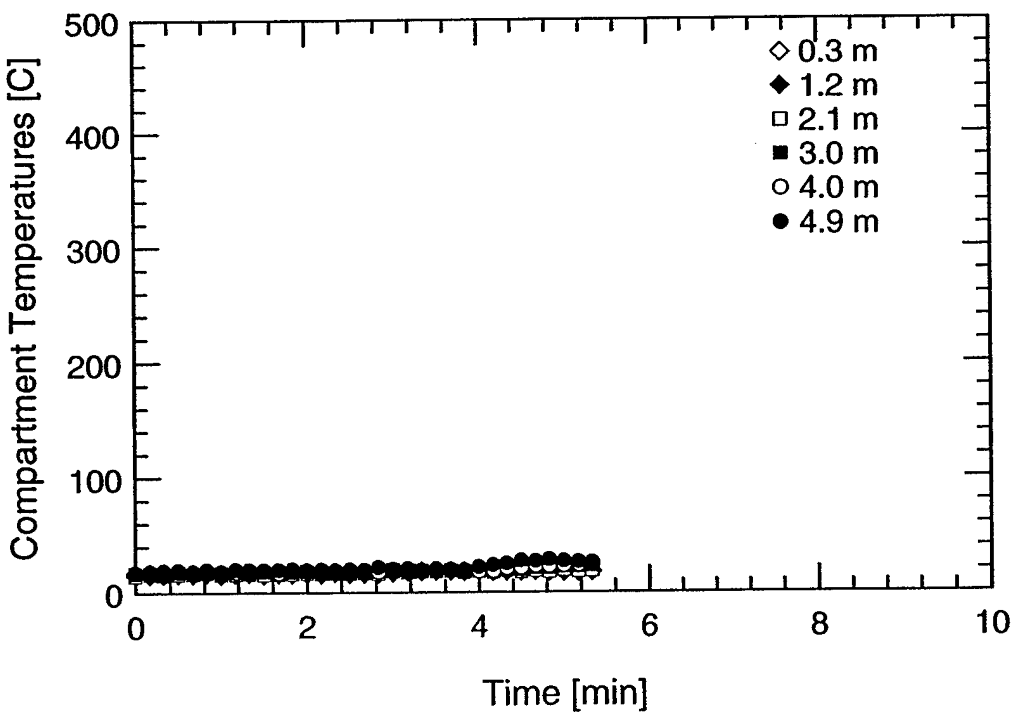


5-27-1

Test #37

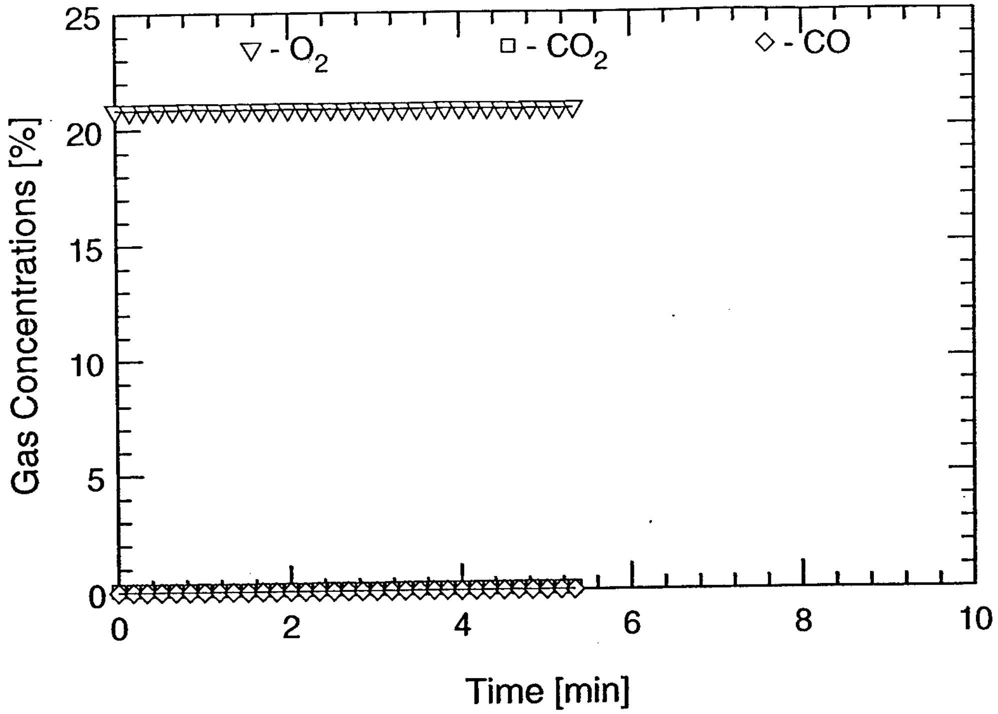


5-27-2

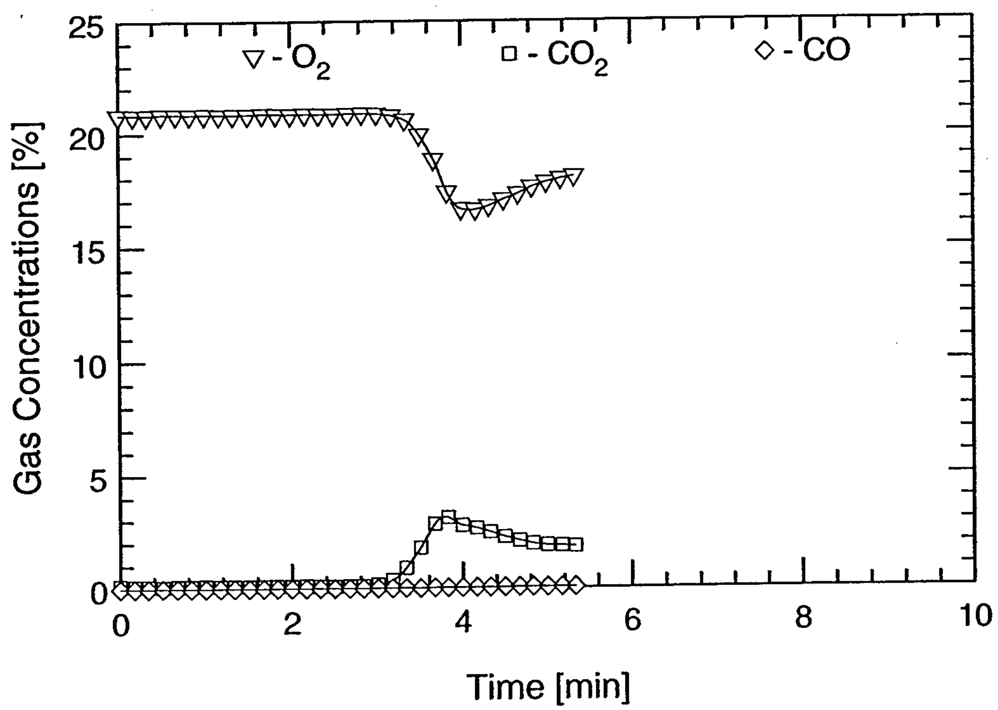


5-35-1

Test #37

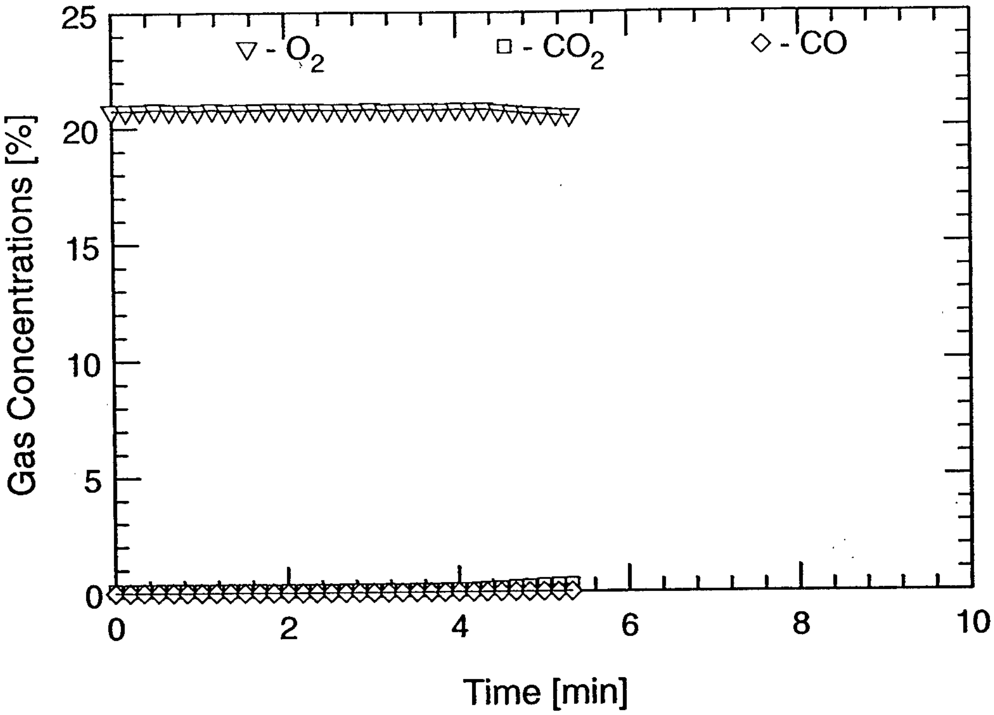


FR 22 - 0.5 m

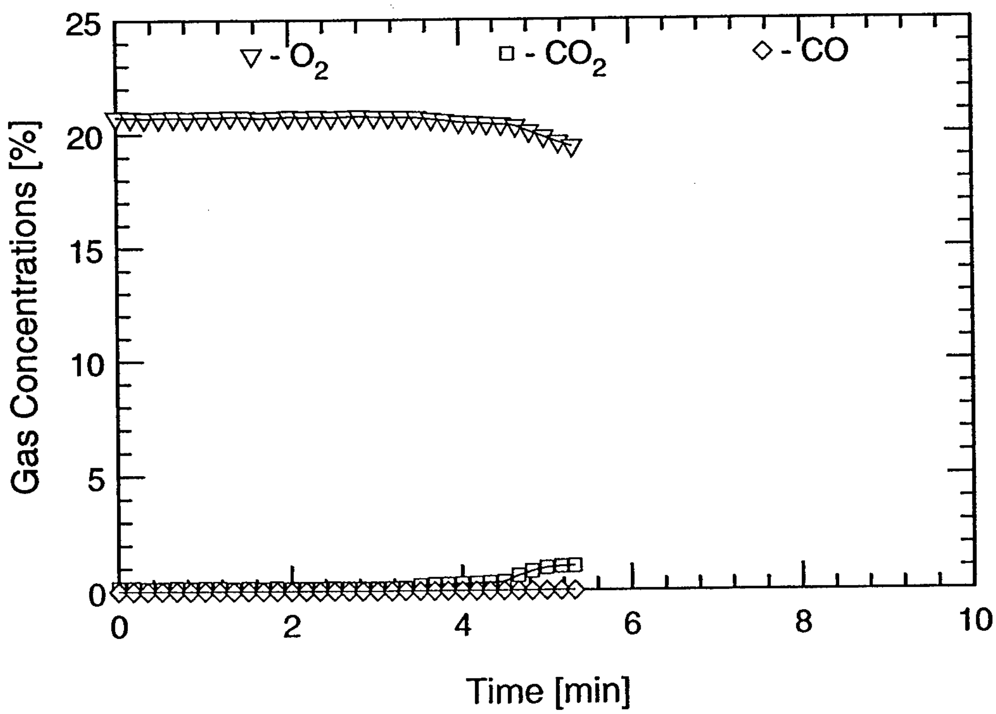


FR 22 - 4.5 m

Test #37

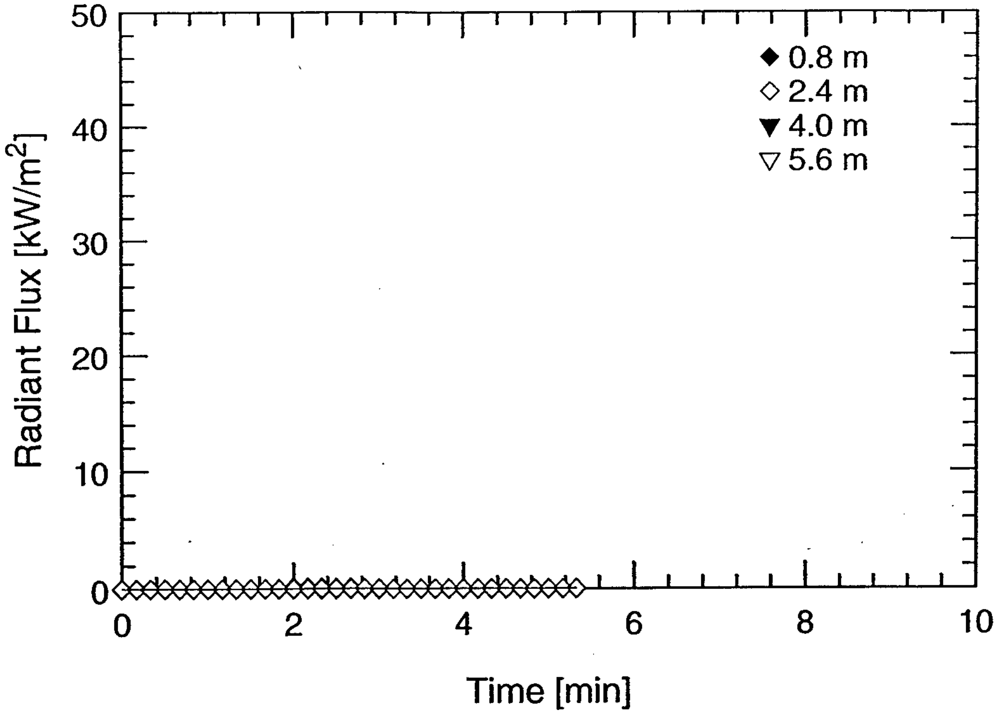


FR 36 - 0.5 m

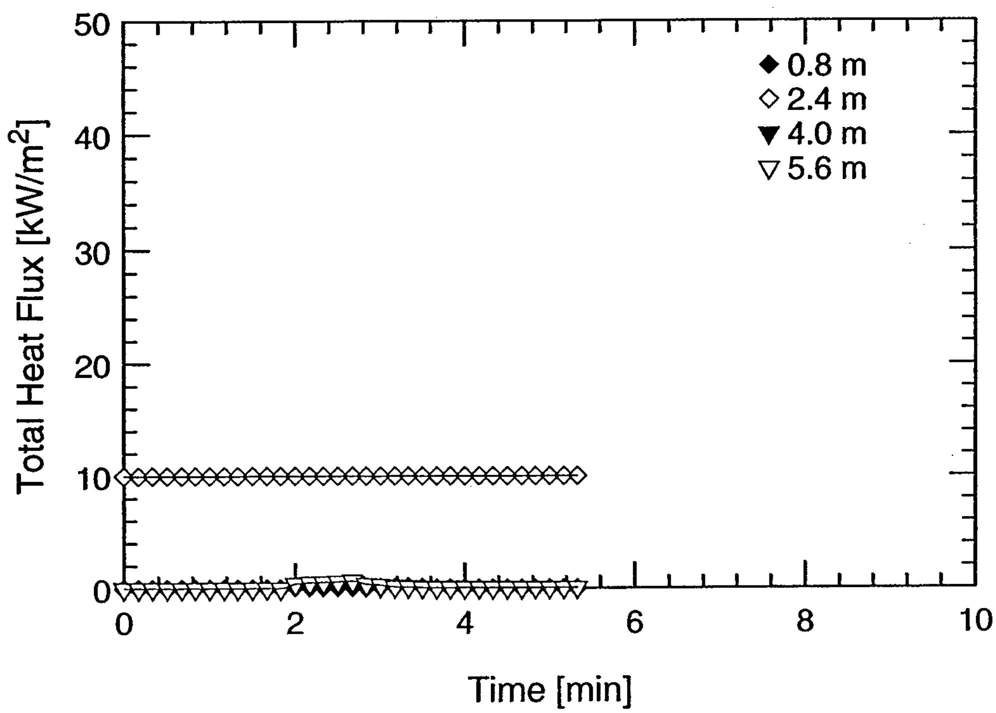


FR 36 - 4.5 m

Test #37

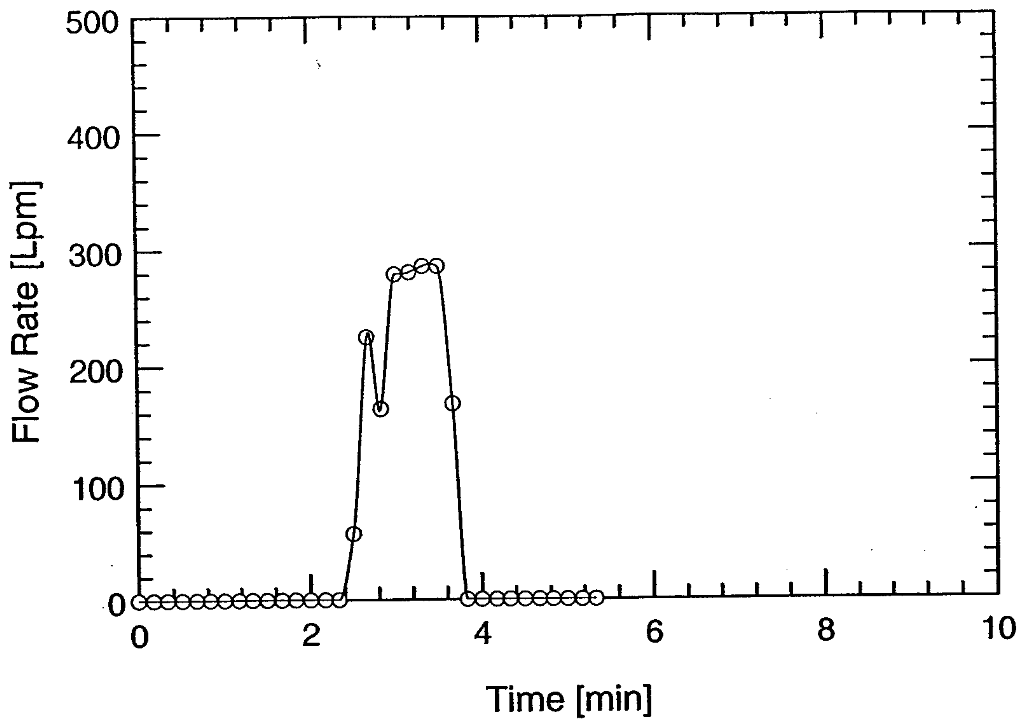


FR 22

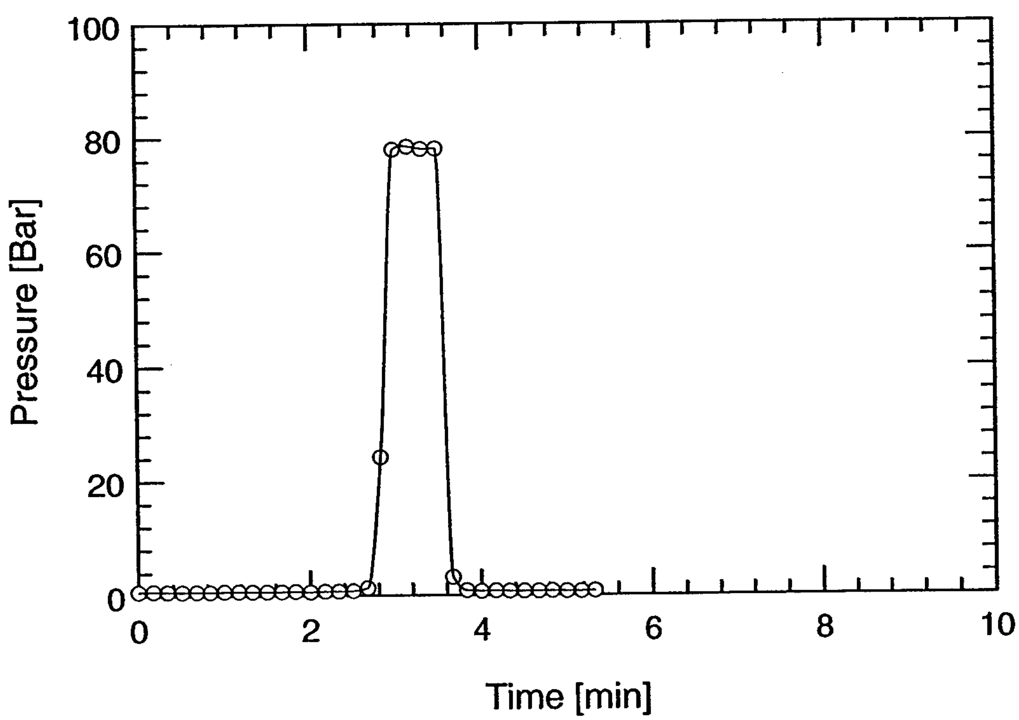


FR 22

Test #37

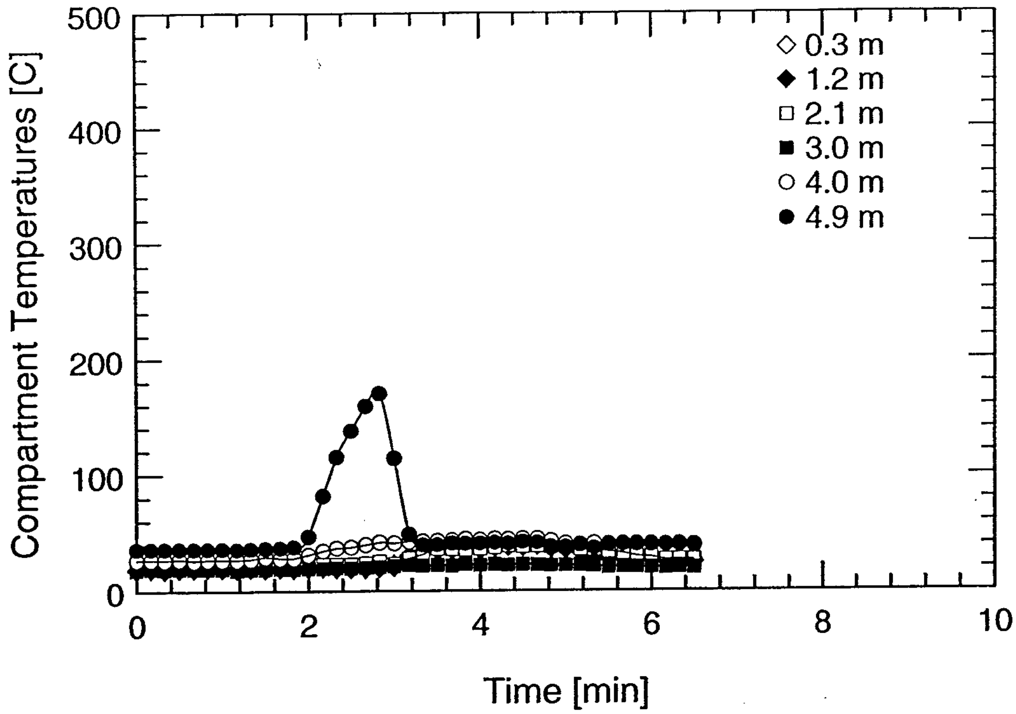


Water Mist System Flow Rate

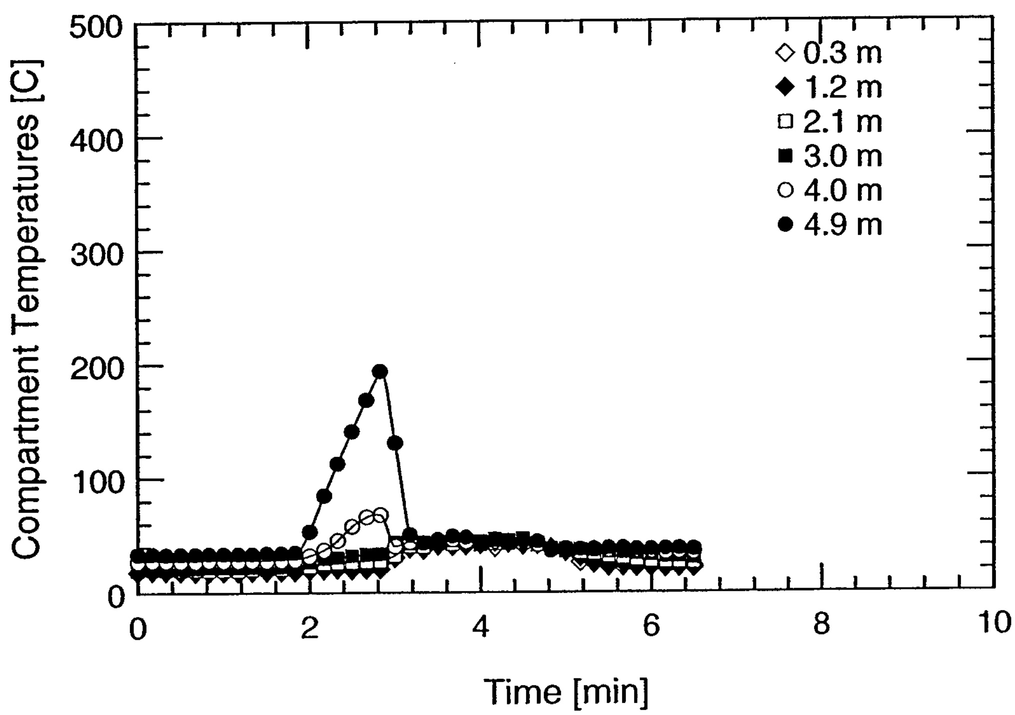


Water Mist System Pressure

Test #37

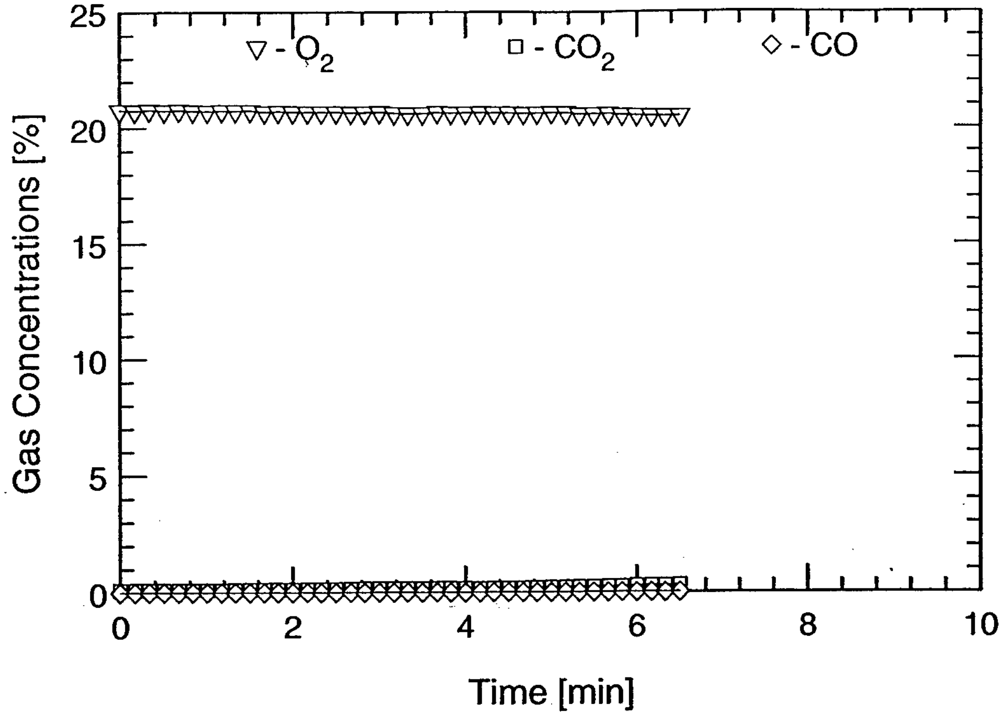


5-22-1

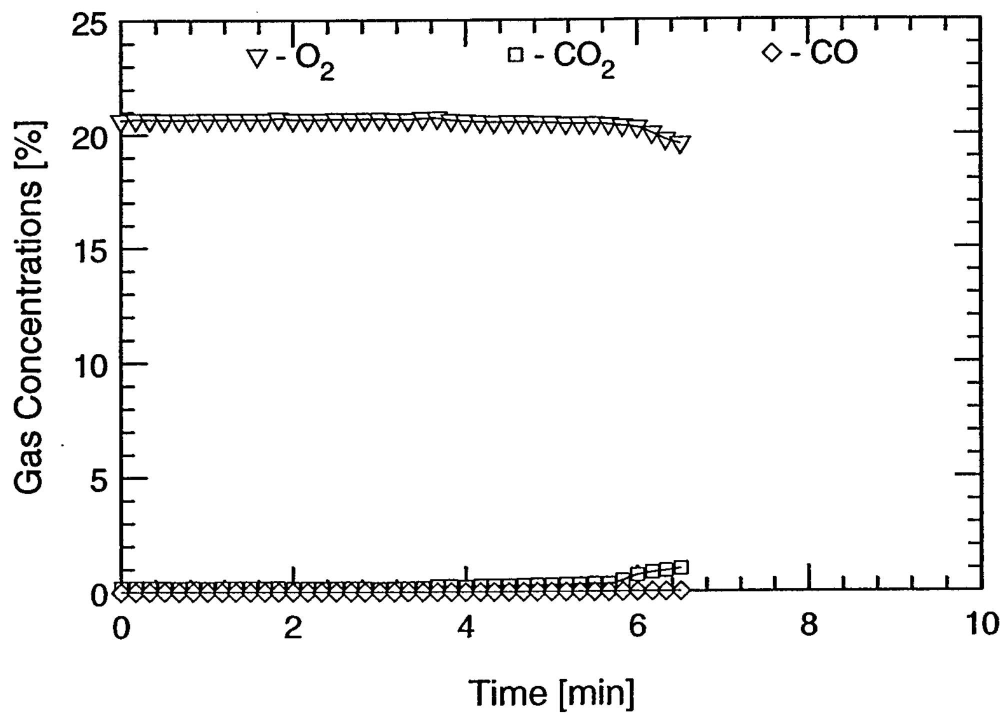


5-27-1

Test #38

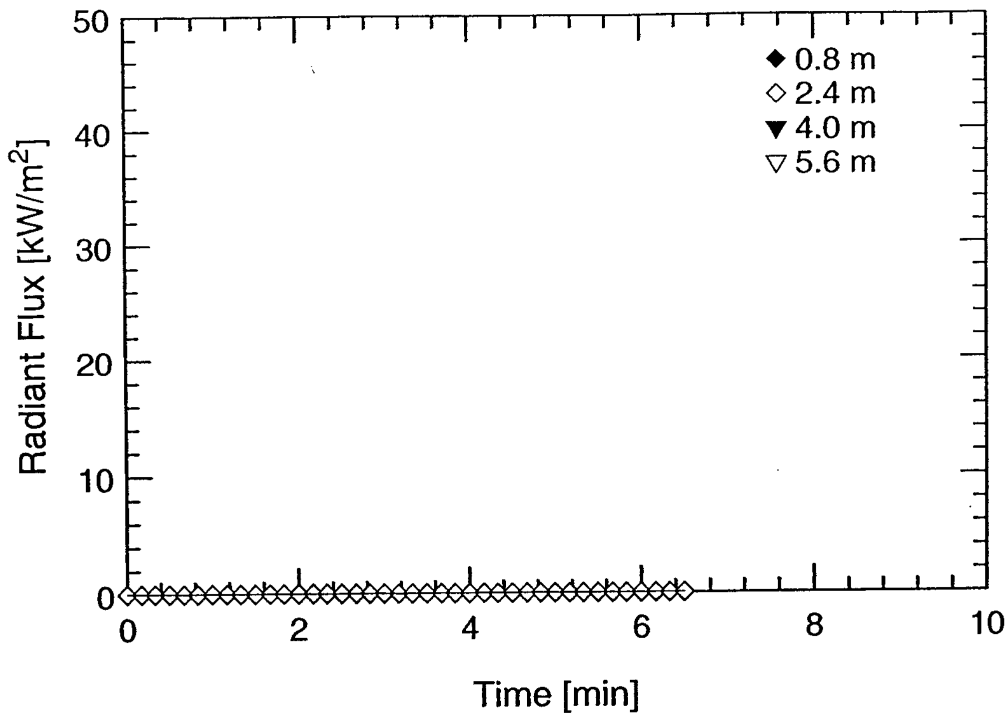


FR 36 - 0.5 m

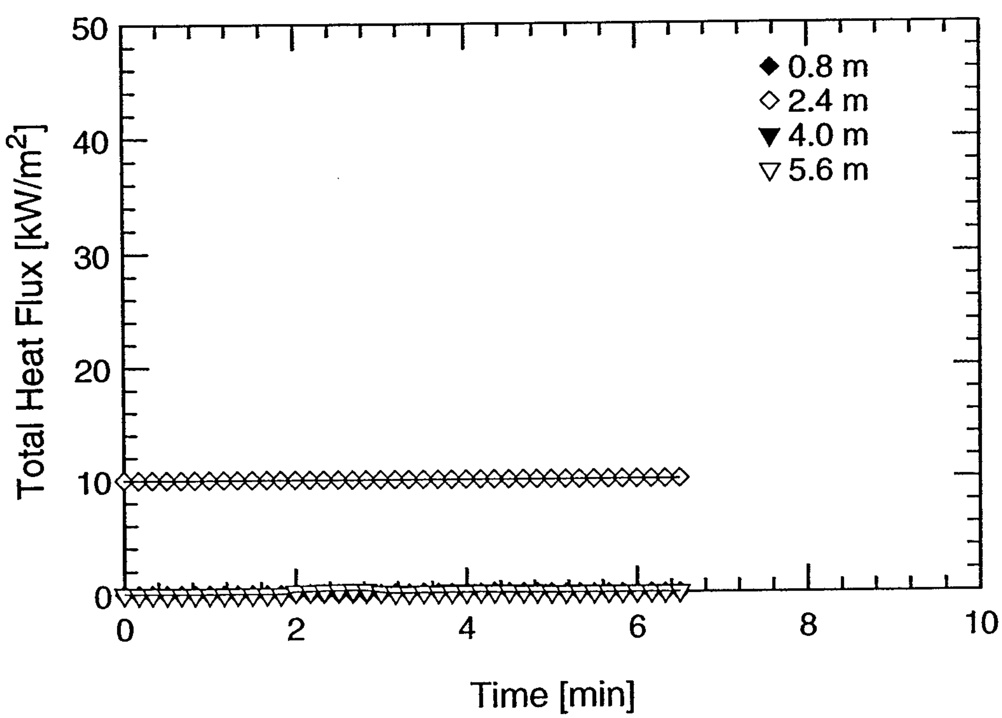


FR 36 - 4.5 m

Test #38

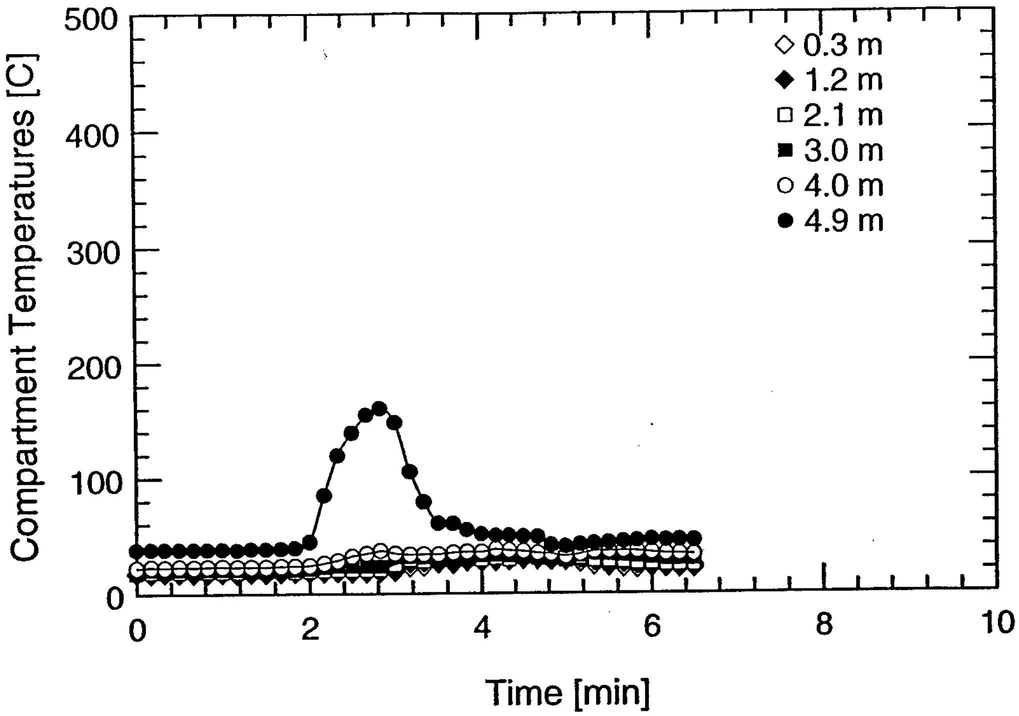


FR 22

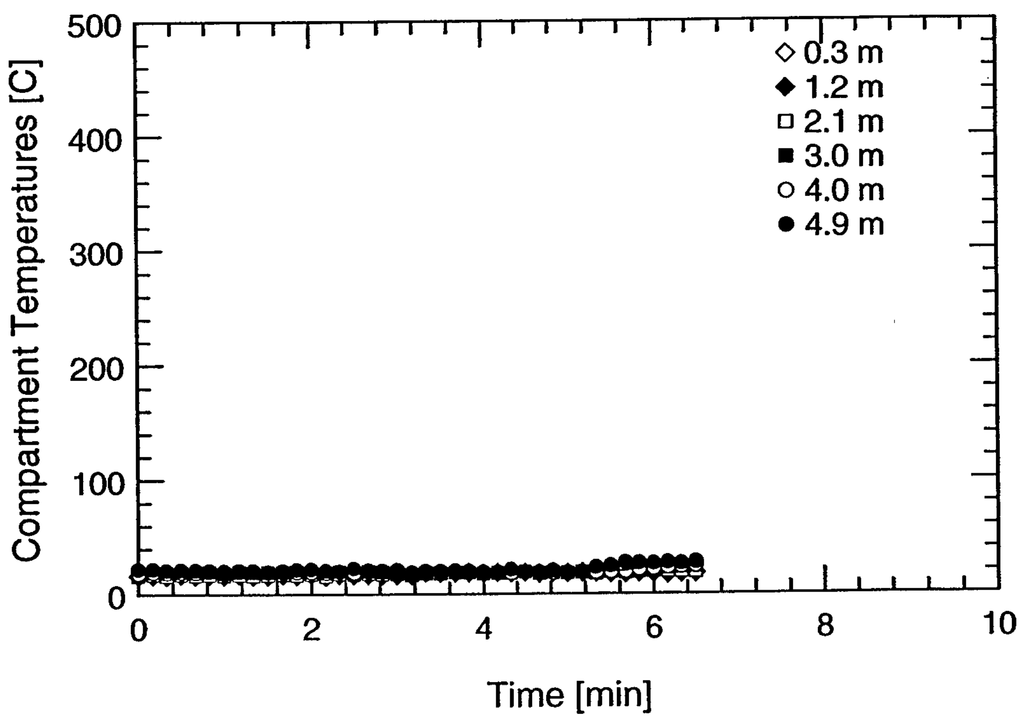


FR 22

Test #38

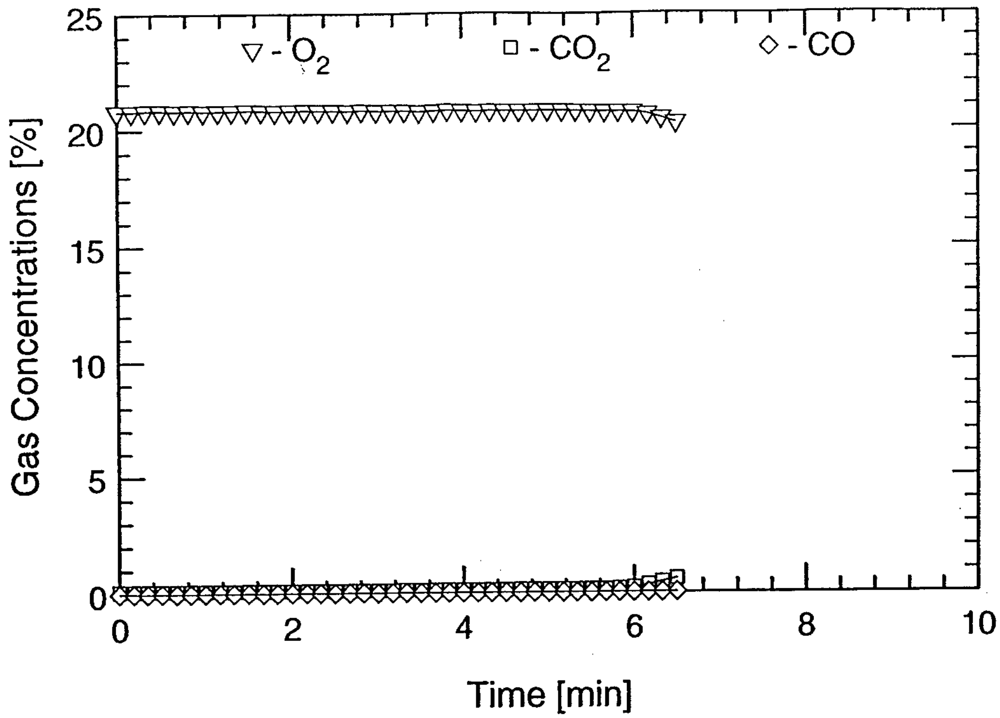


5-27-2

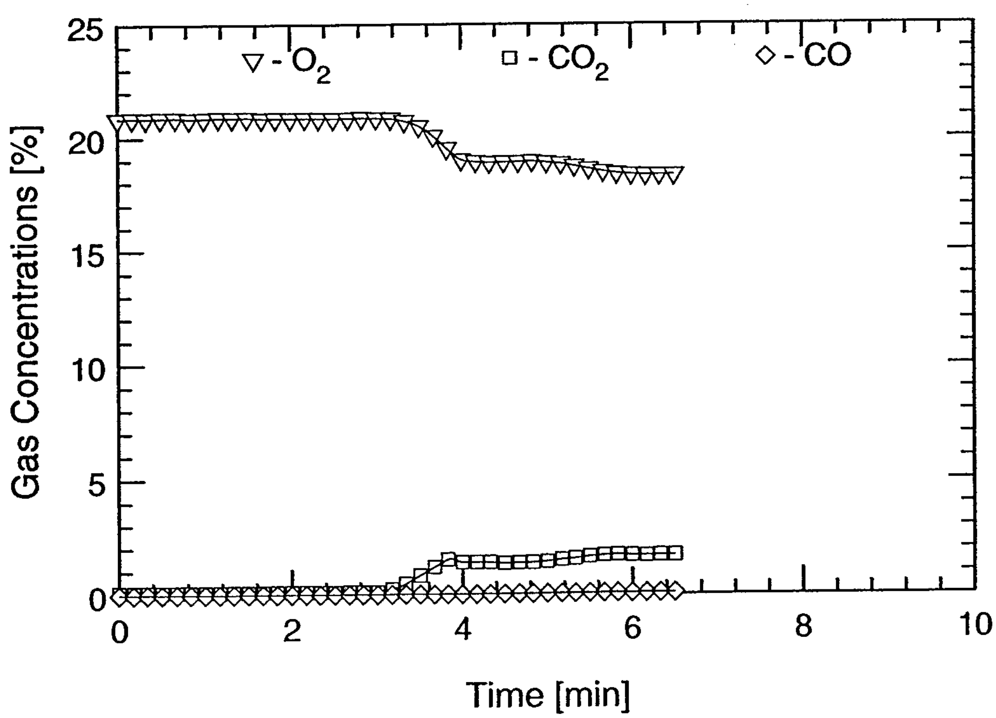


5-35-1

Test #38

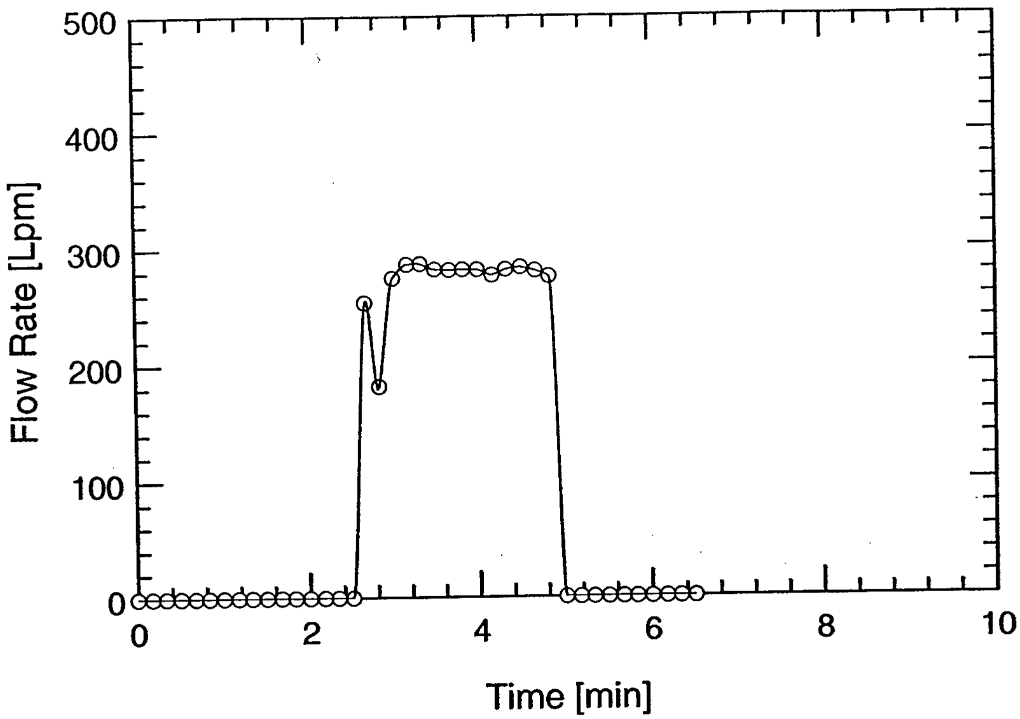


FR 22 - 0.5 m

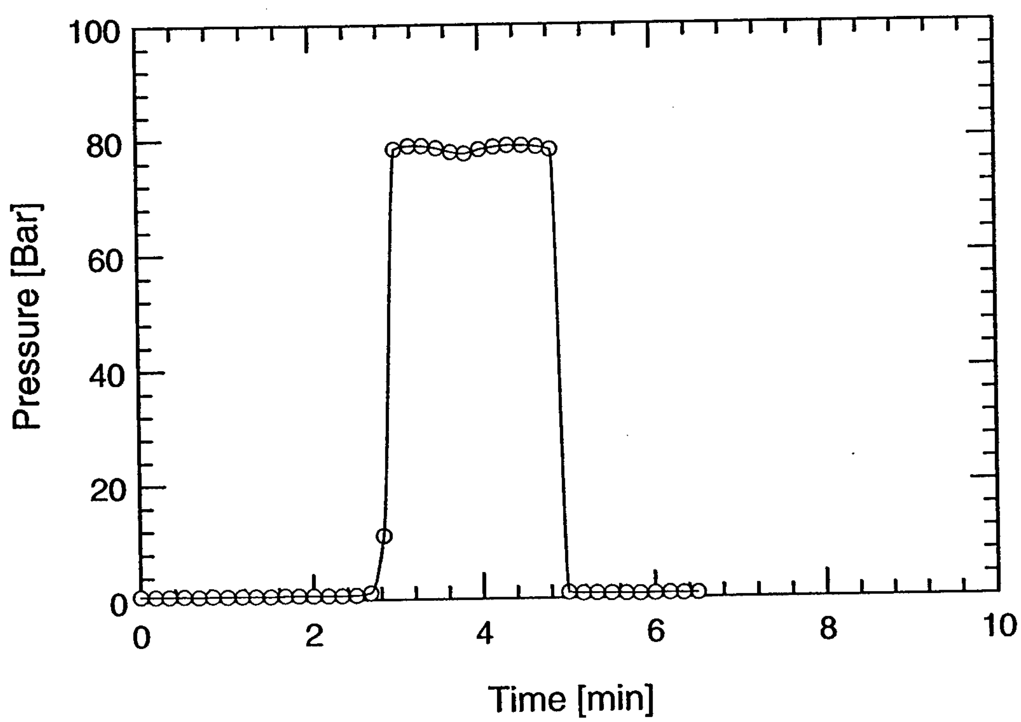


FR 22 - 4.5 m

Test #38

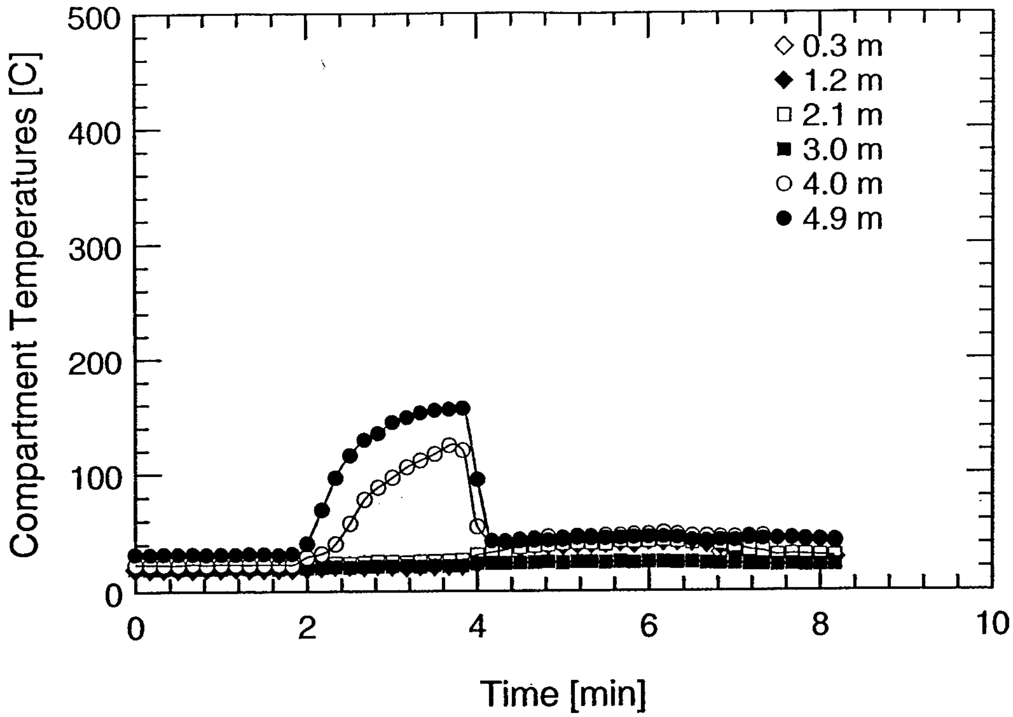


Water Mist System Flow Rate

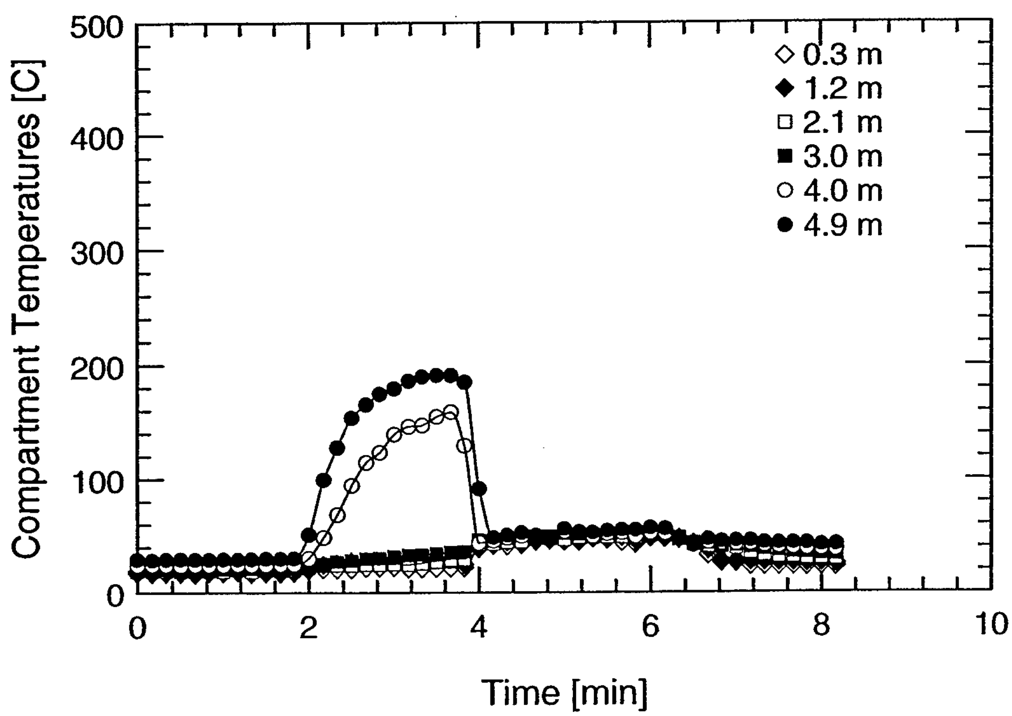


Water Mist System Pressure

Test #38

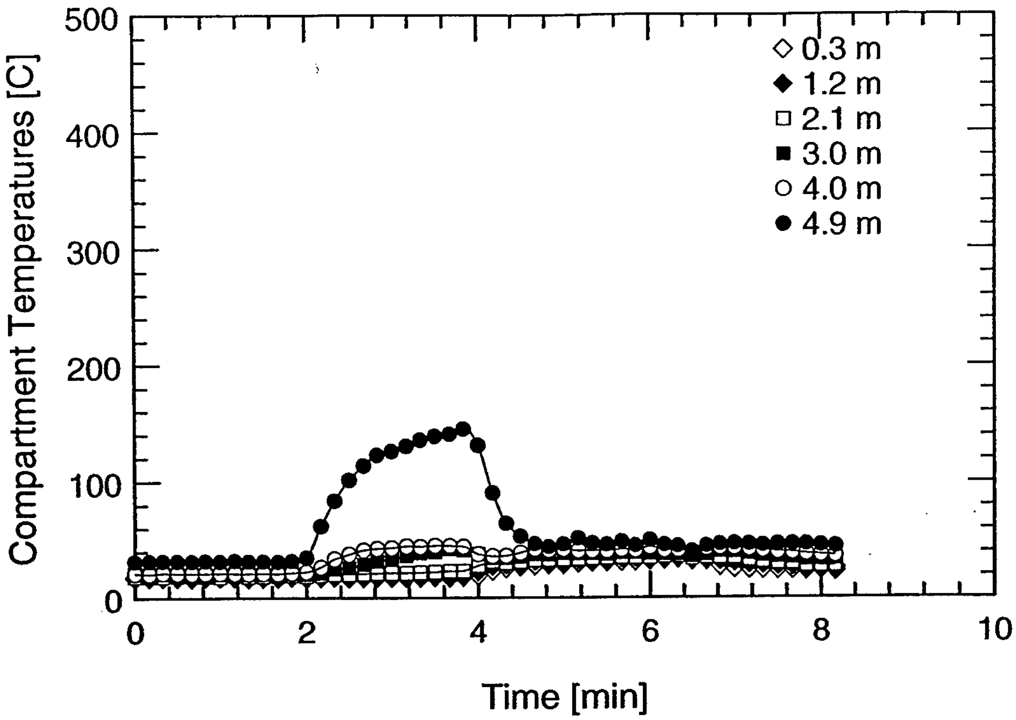


5-22-1

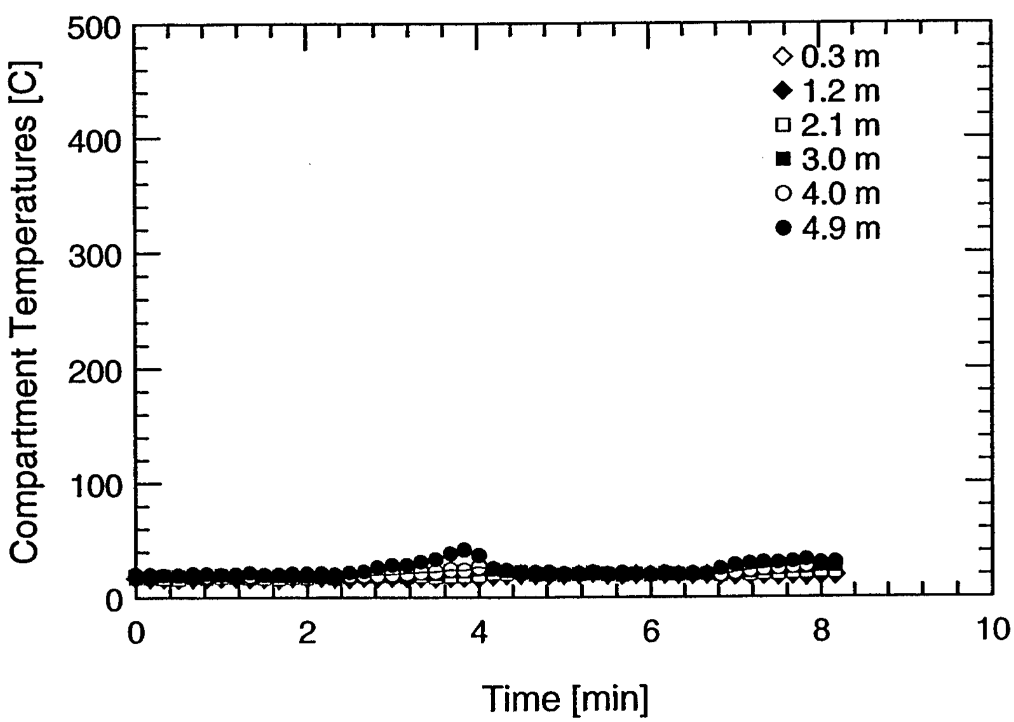


5-27-1

Test #39

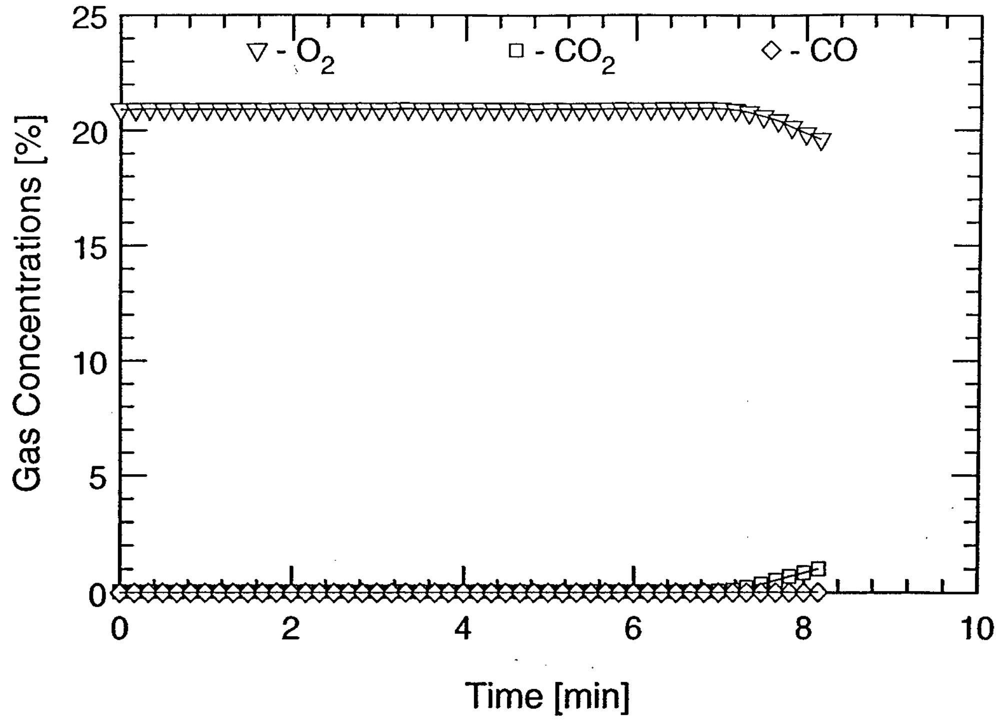


5-27-2

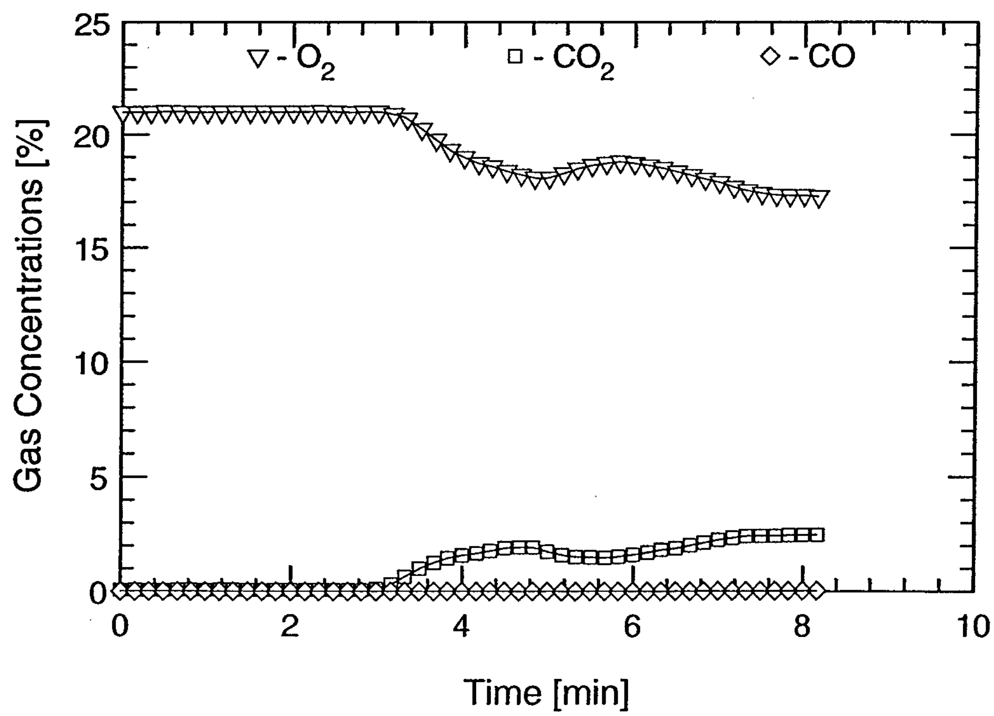


5-35-1

Test #39

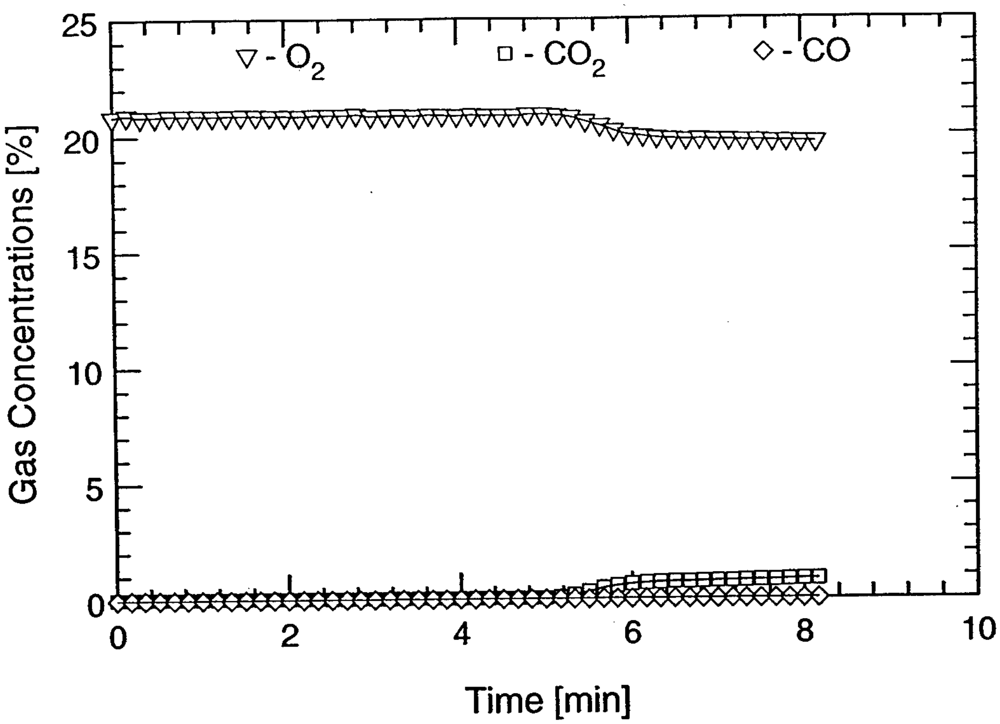


FR 22 - 0.5 m

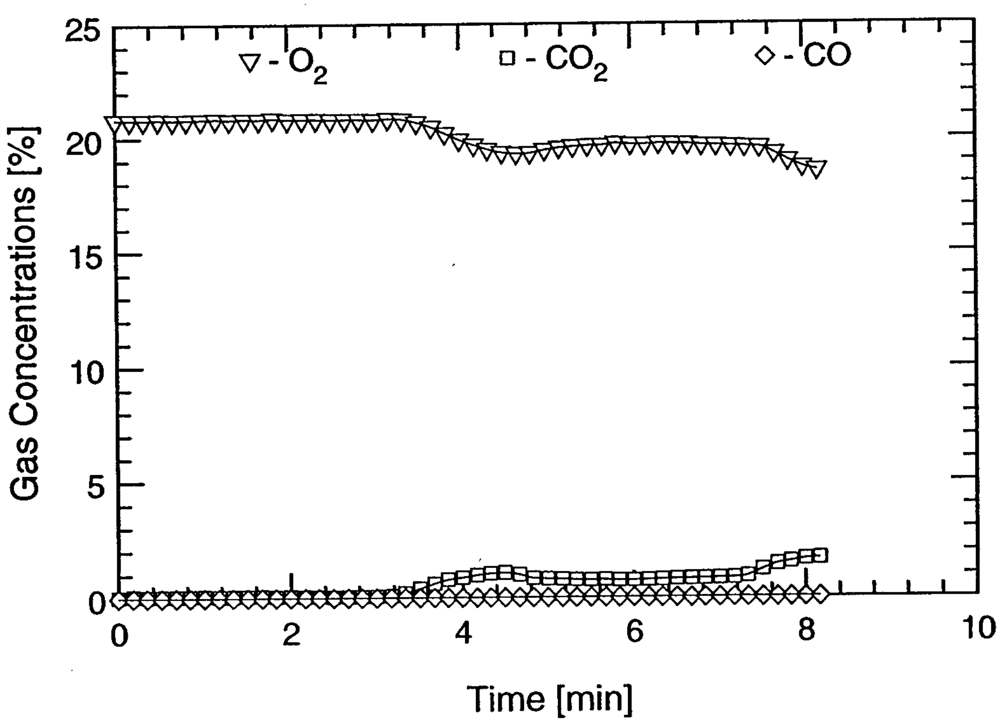


FR 22 - 4.5 m

Test #39

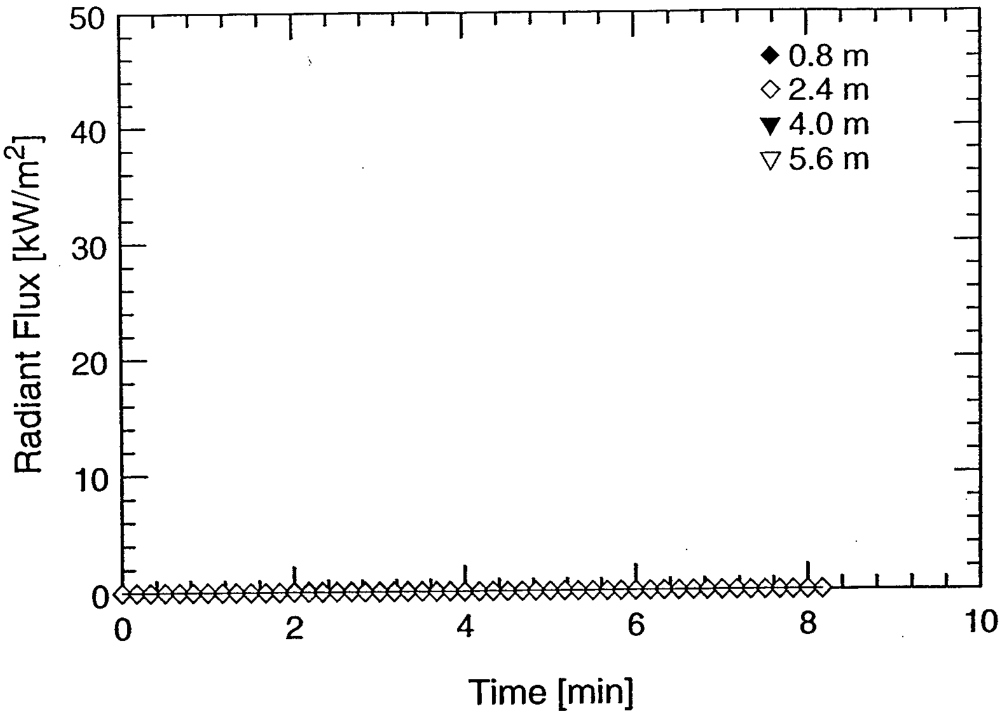


FR 36 - 0.5 m

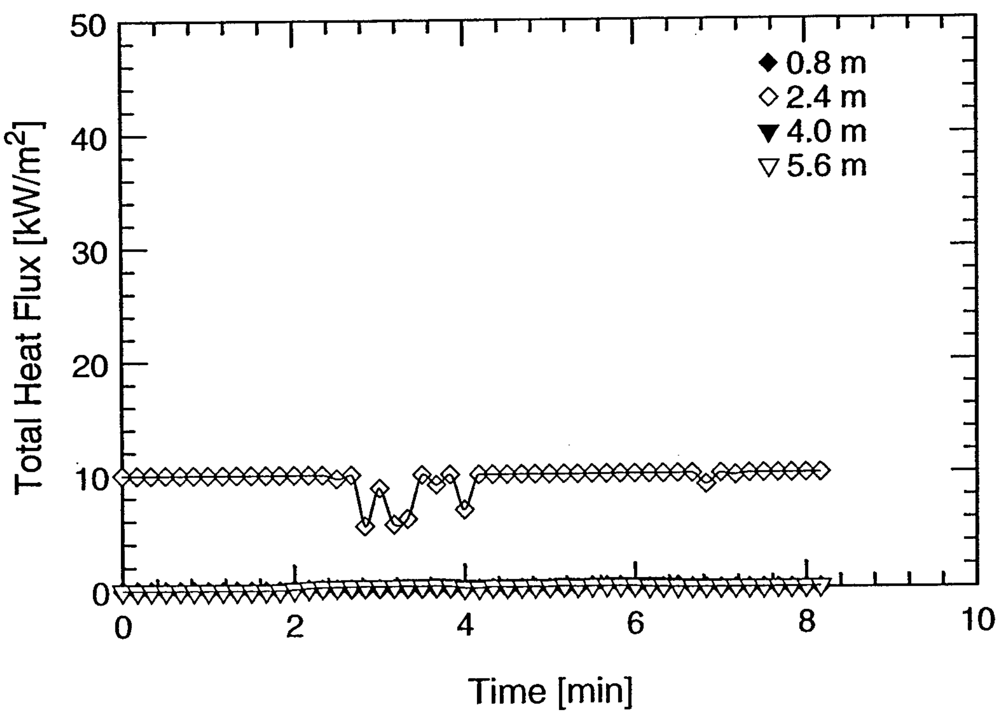


FR 36 - 4.5 m

Test #39

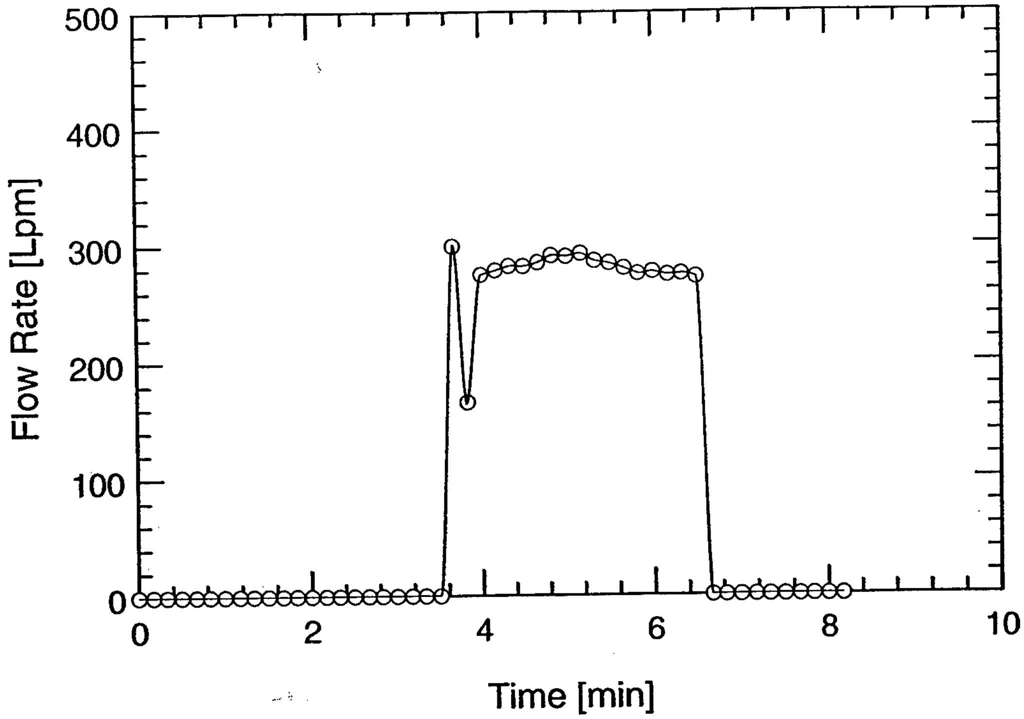


FR 22

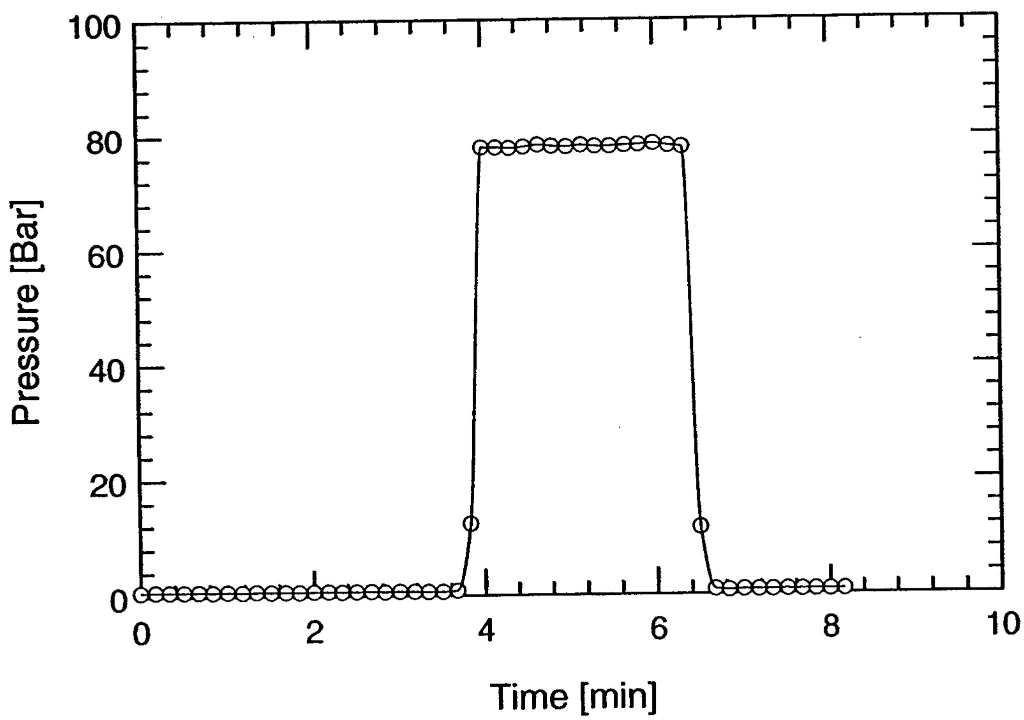


FR 22

Test #39

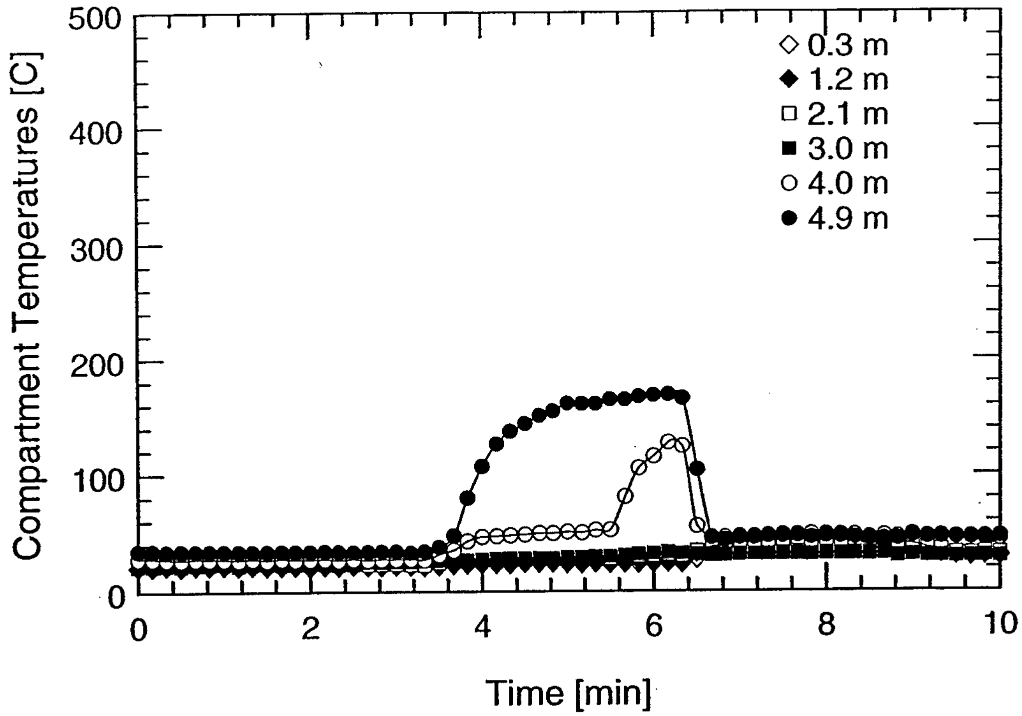


Water Mist System Flow Rate

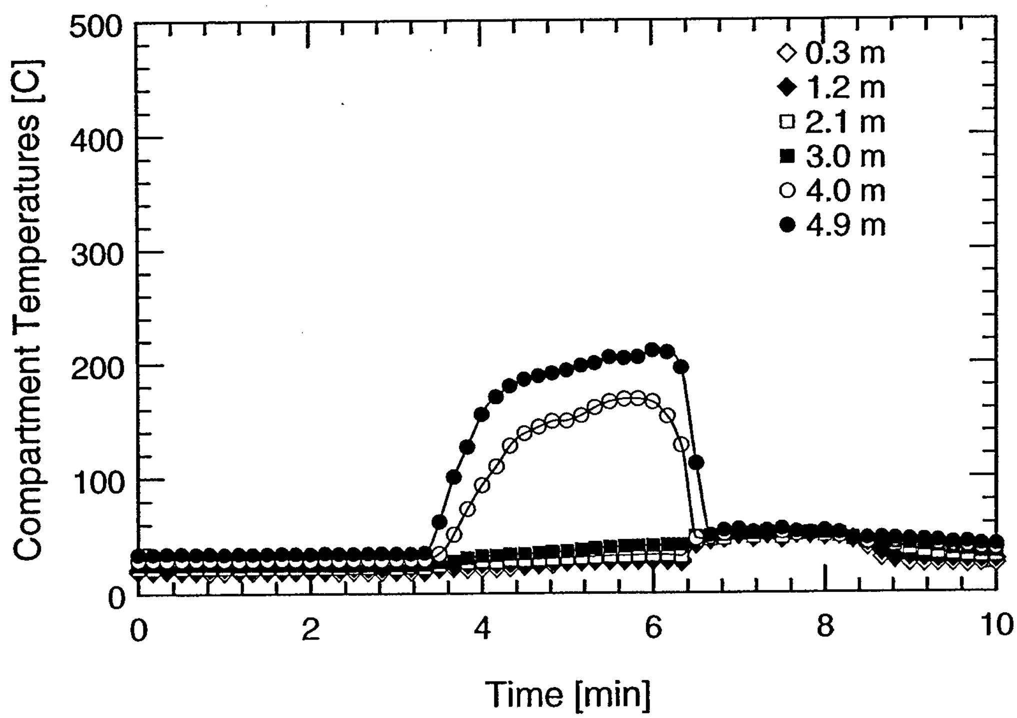


Water Mist System Pressure

Test #39

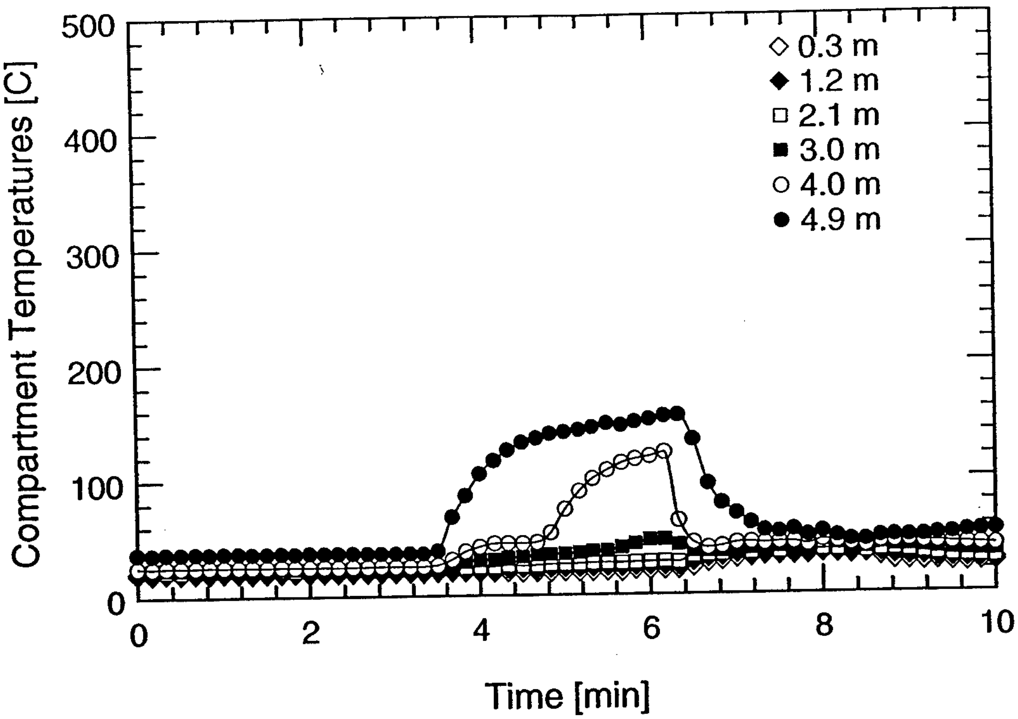


5-22-1

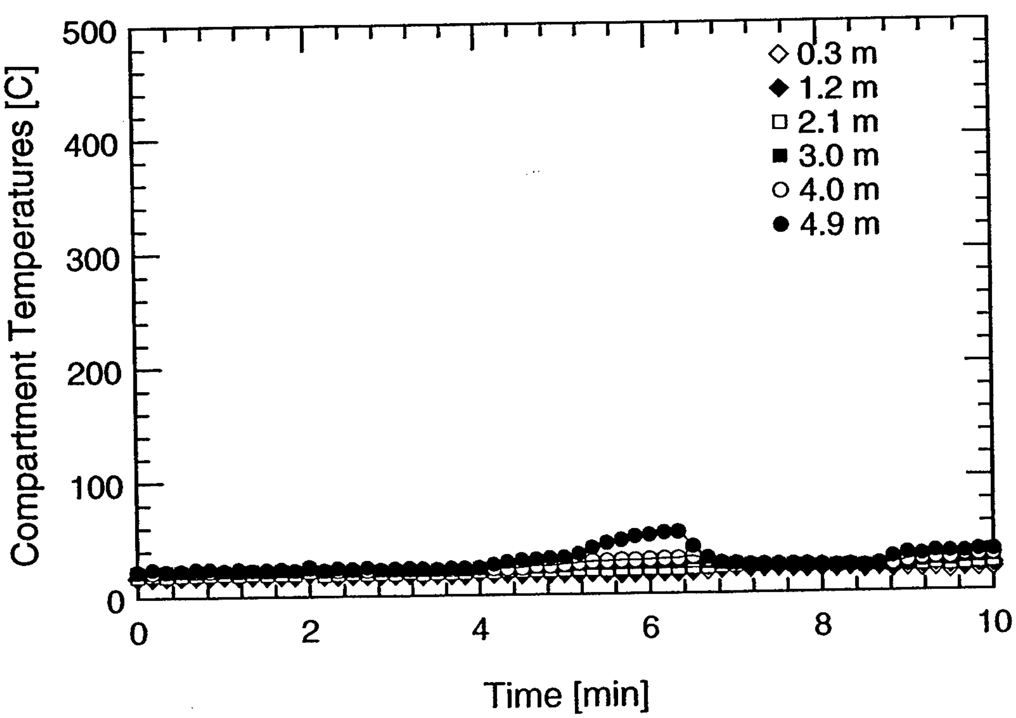


5-27-1

Test #40

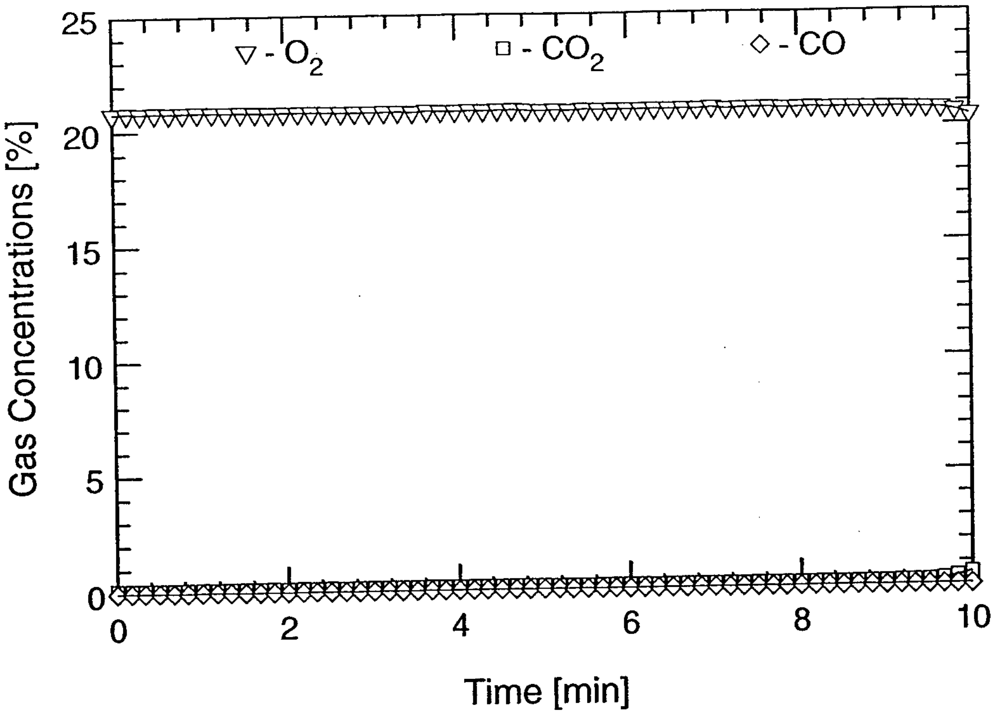


5-27-2

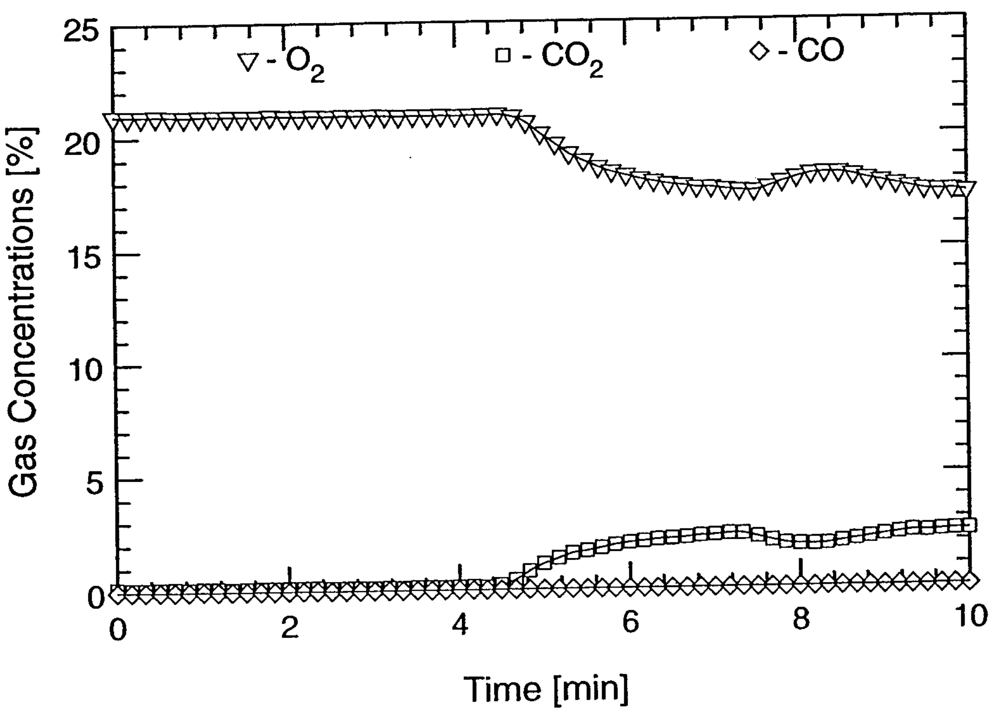


5-35-1

Test #40

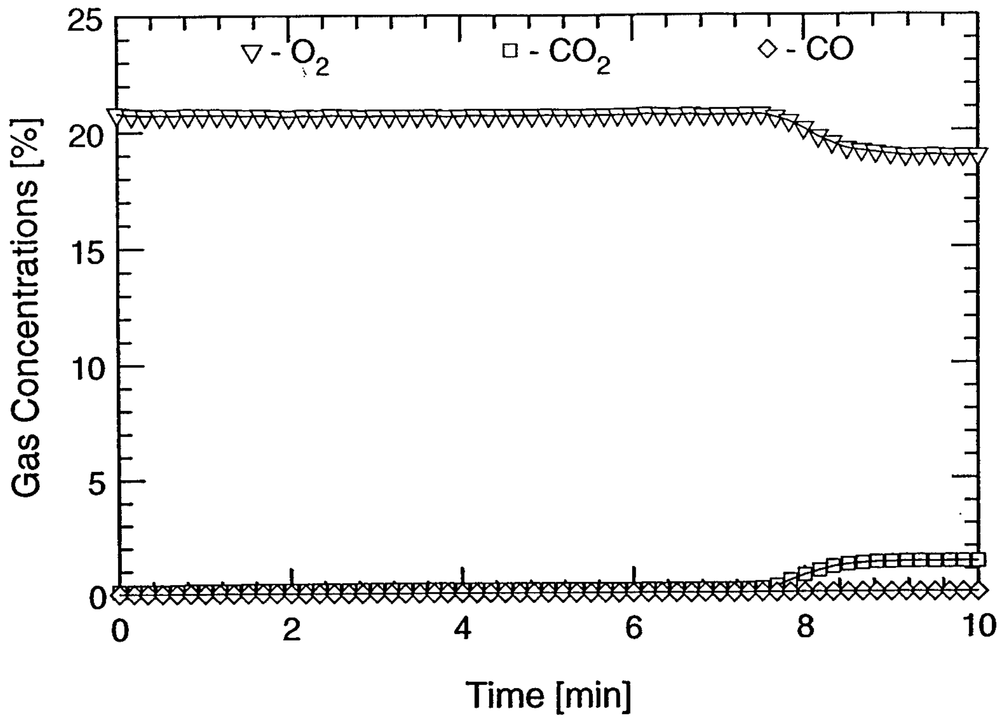


FR 22 - 0.5 m

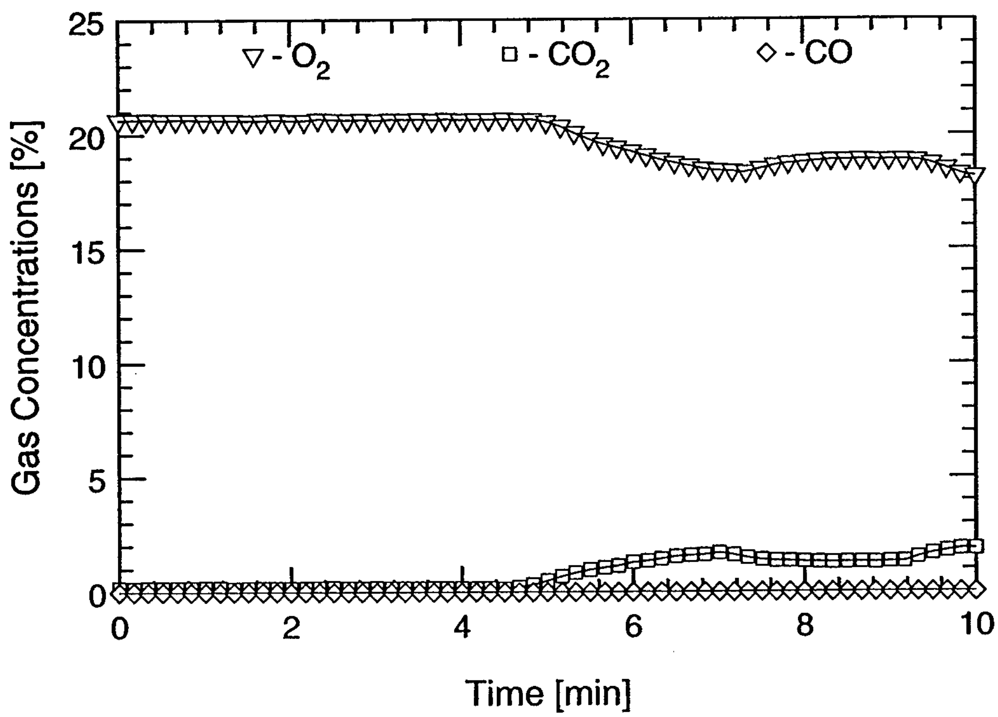


FR 22 - 4.5 m

Test #40

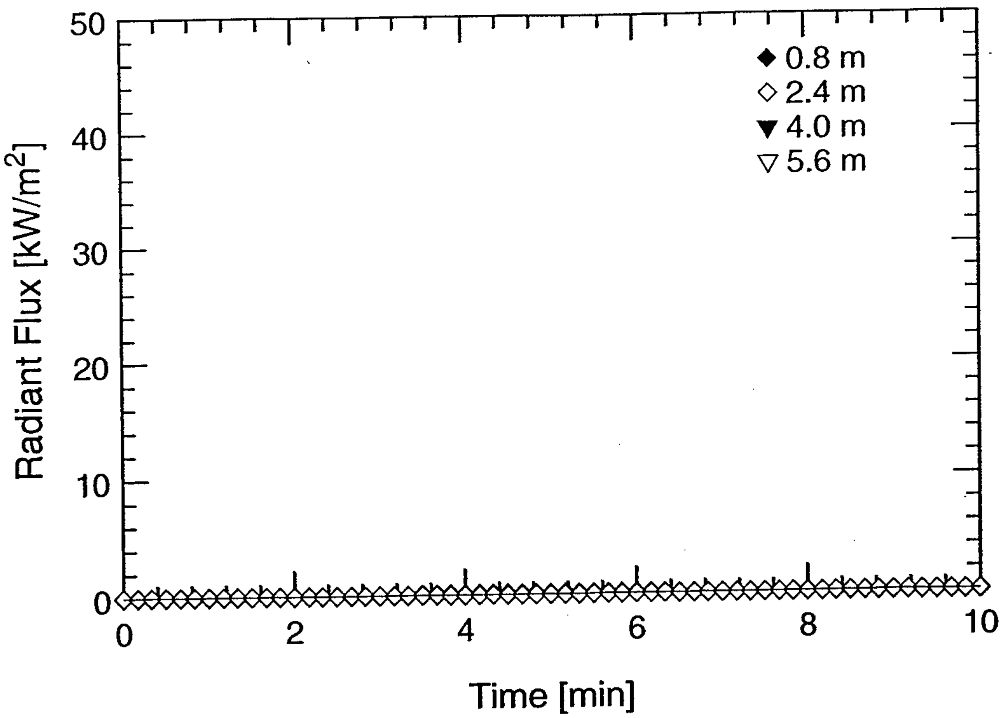


FR 36 - 0.5 m

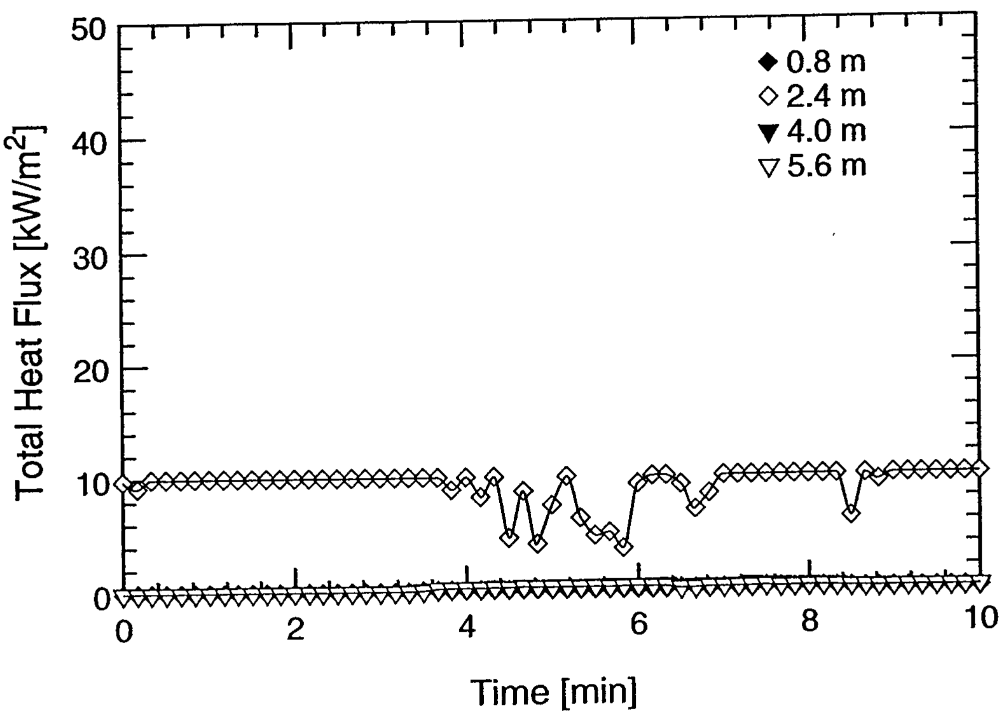


FR 36 - 4.5 m

Test #40

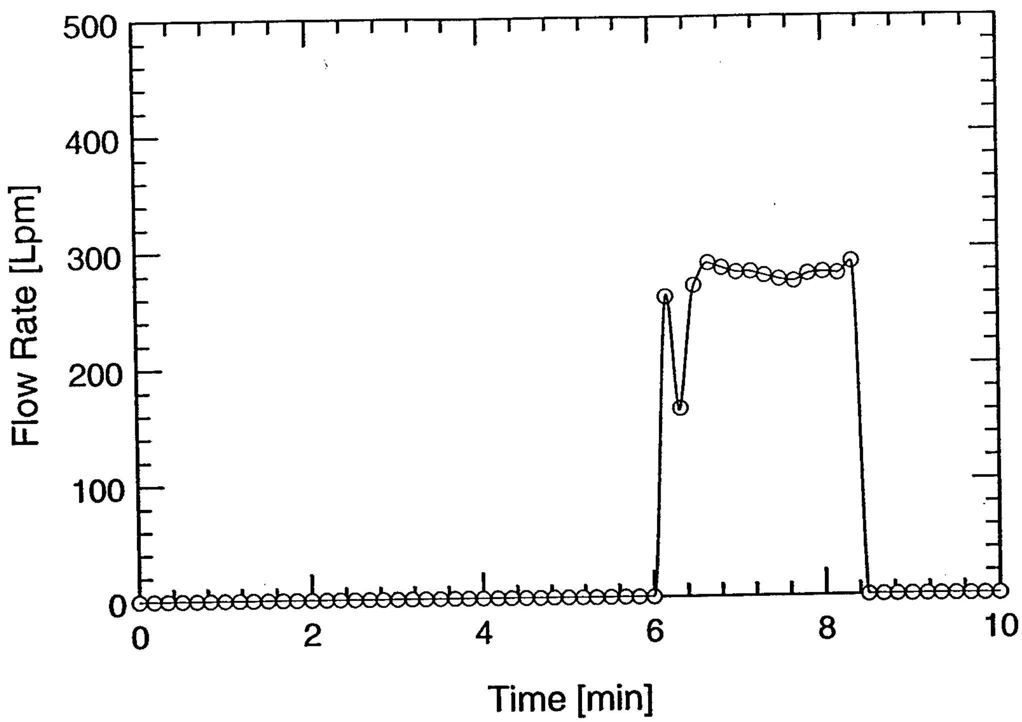


FR 22

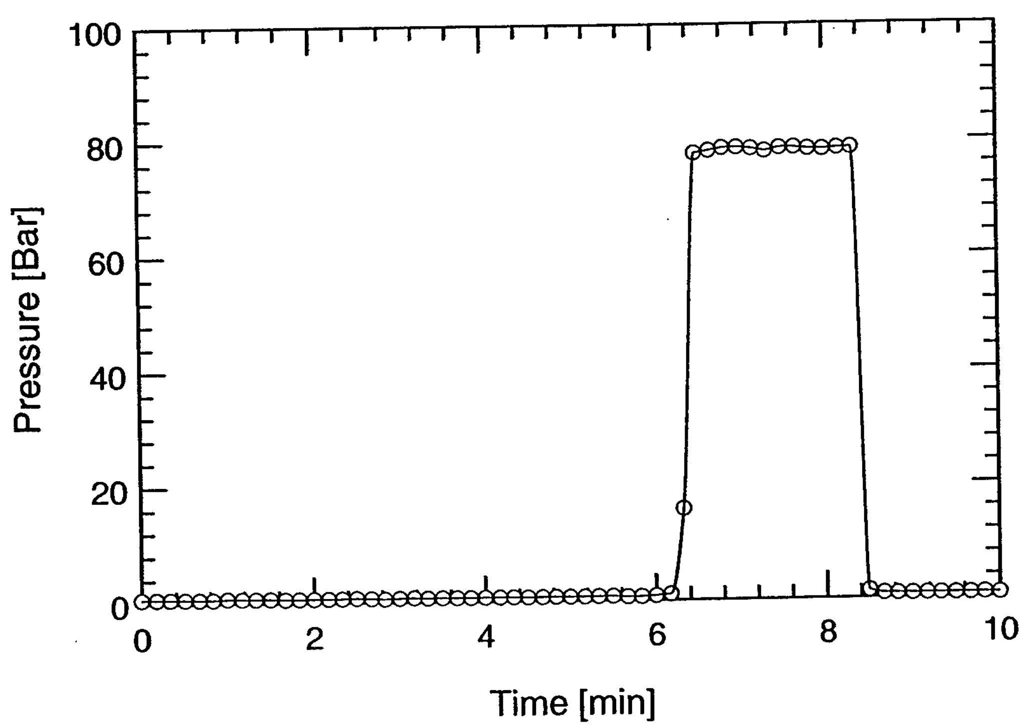


FR 22

Test #40

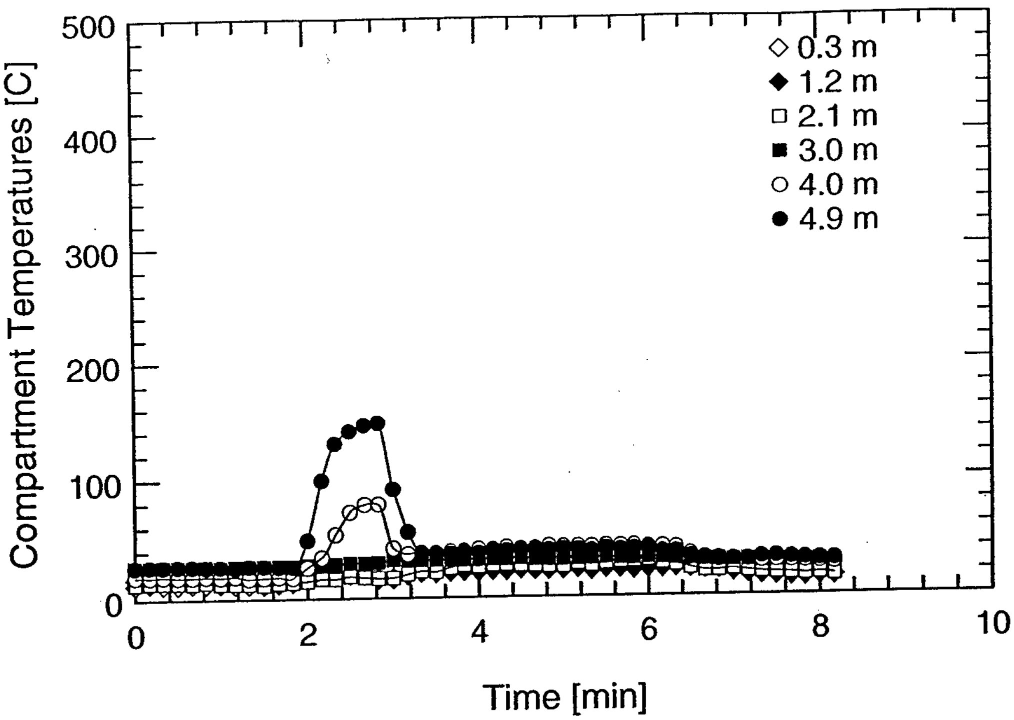


Water Mist System Flow Rate

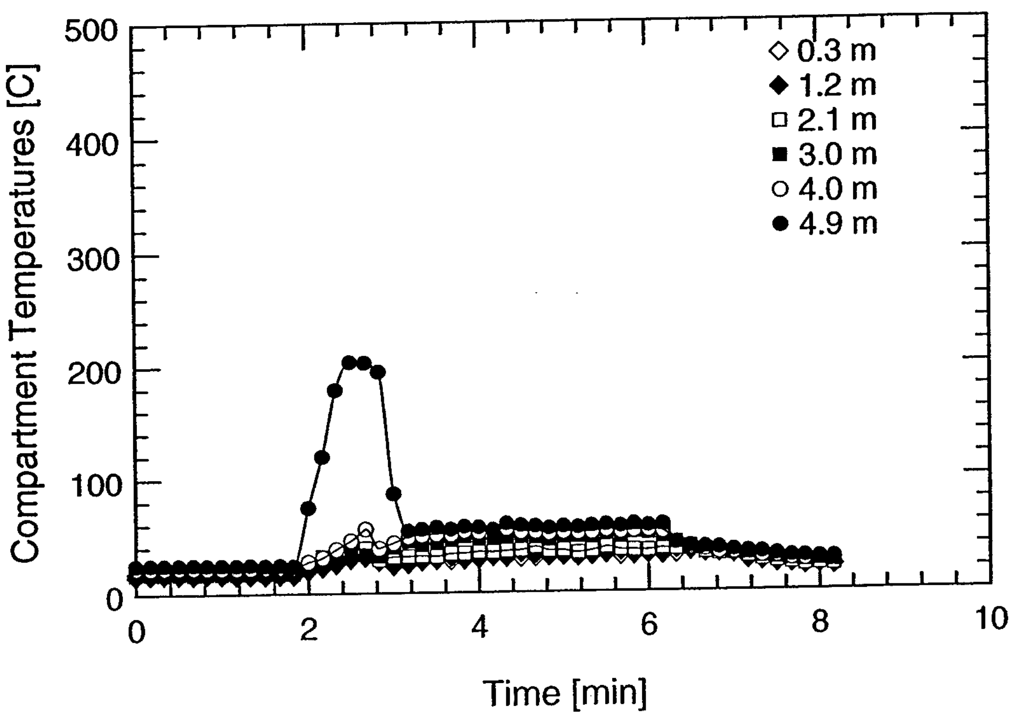


Water Mist System Pressure

Test #40

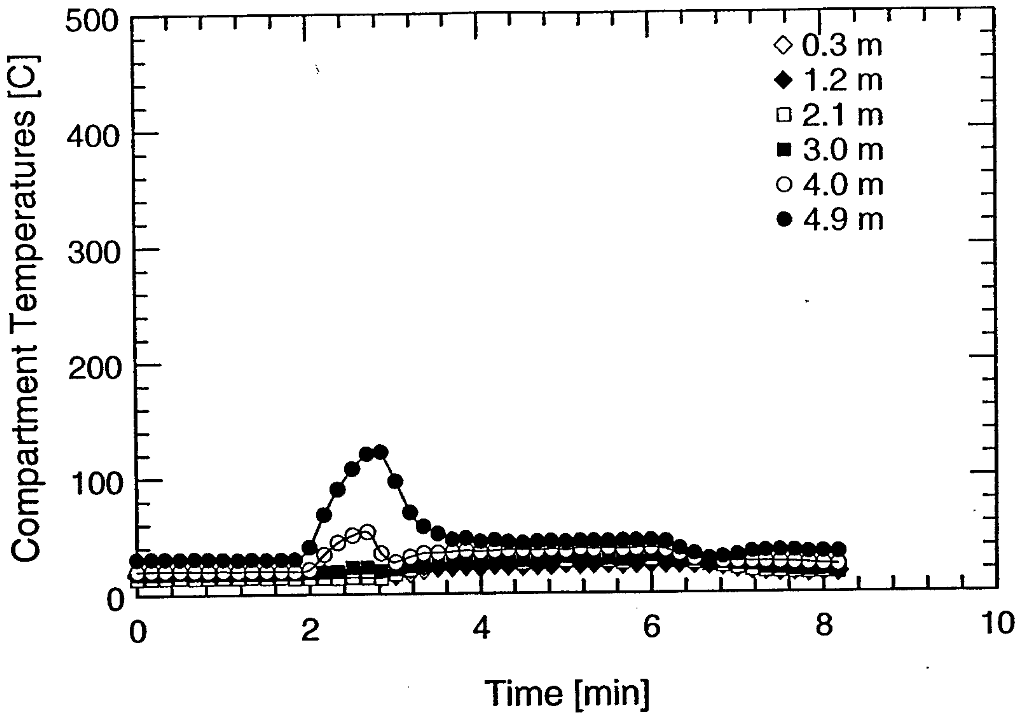


5-22-1

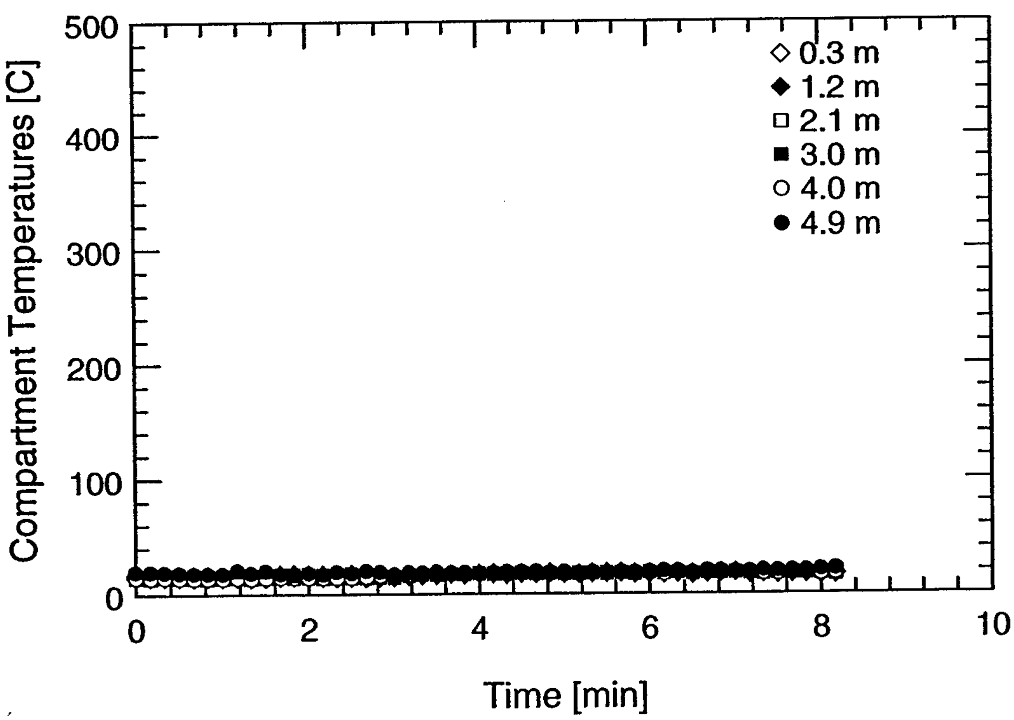


5-27-1

Test #41

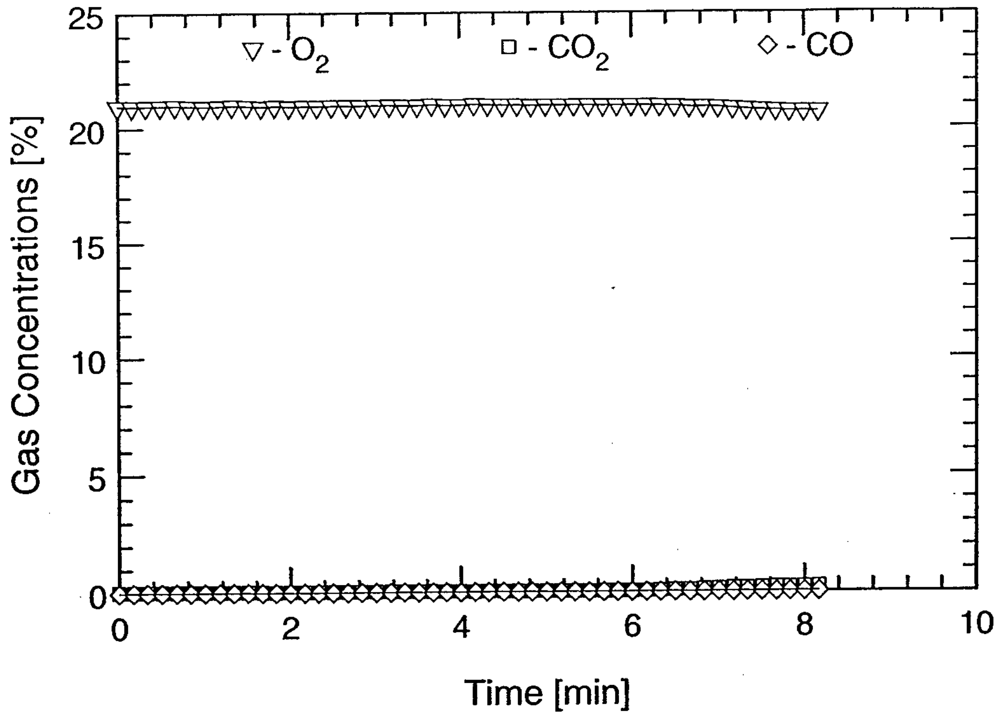


5-27-2

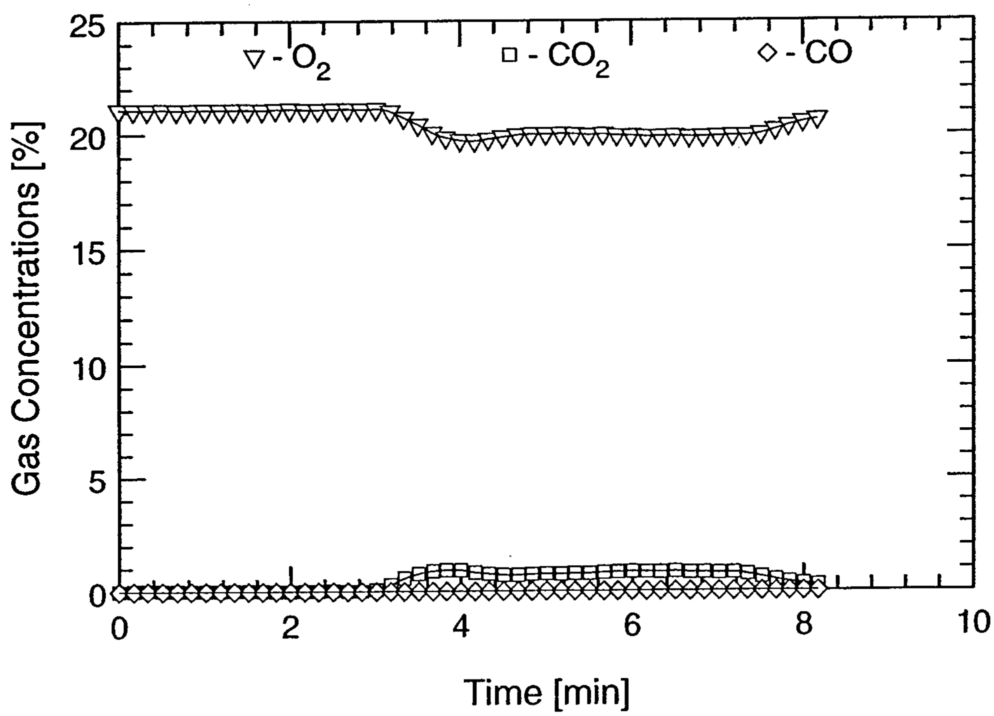


5-35-1

Test #41

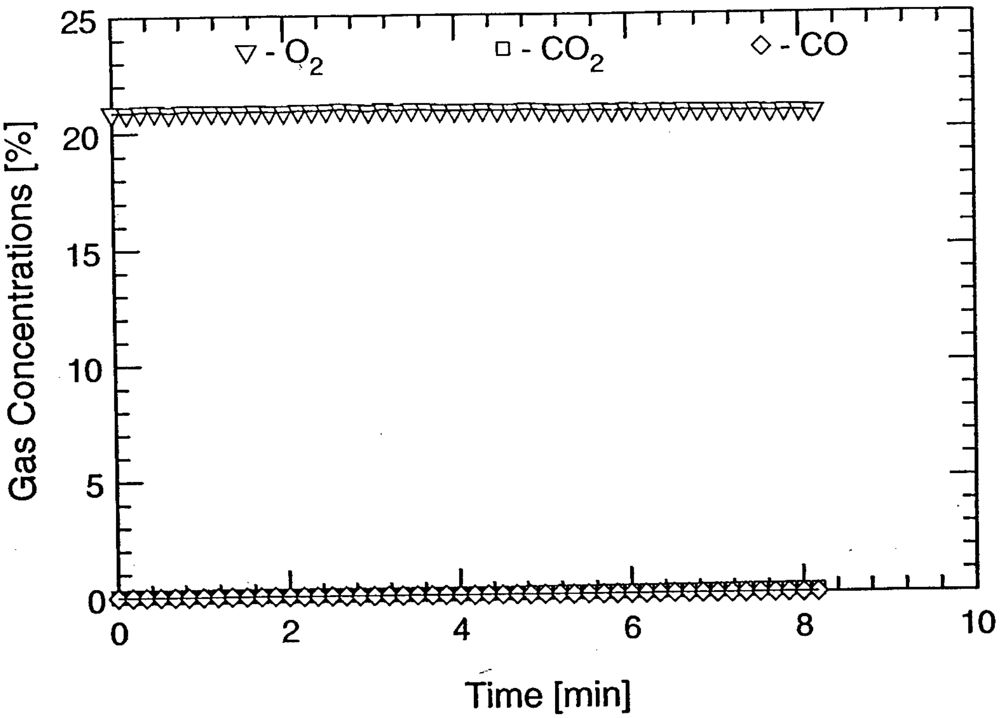


FR 22 - 0.5 m

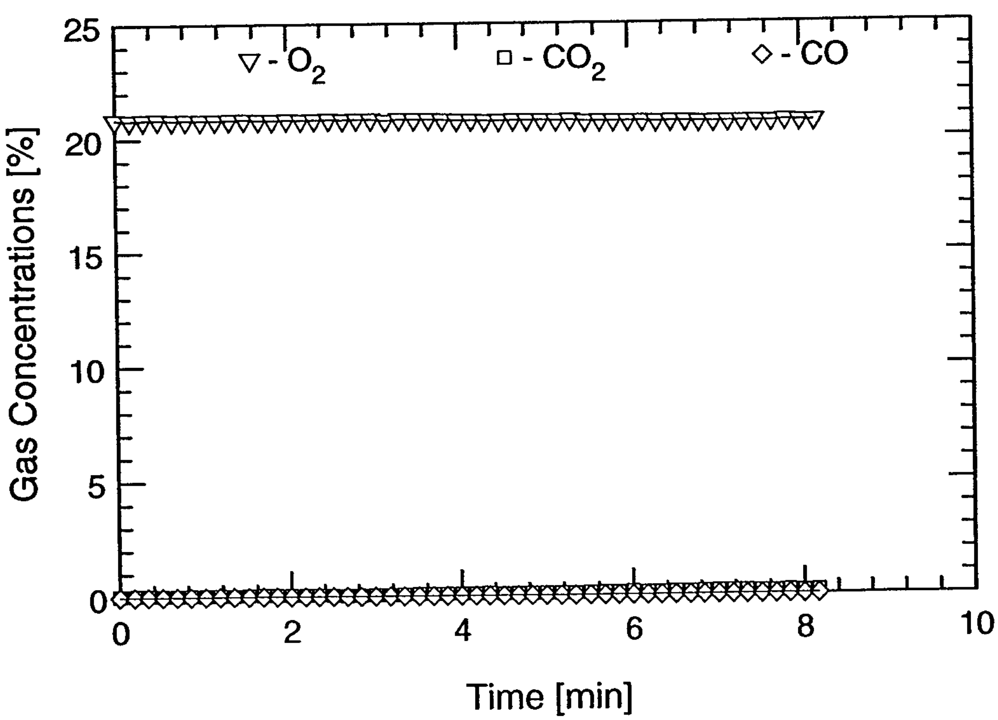


FR 22 - 4.5 m

Test #41

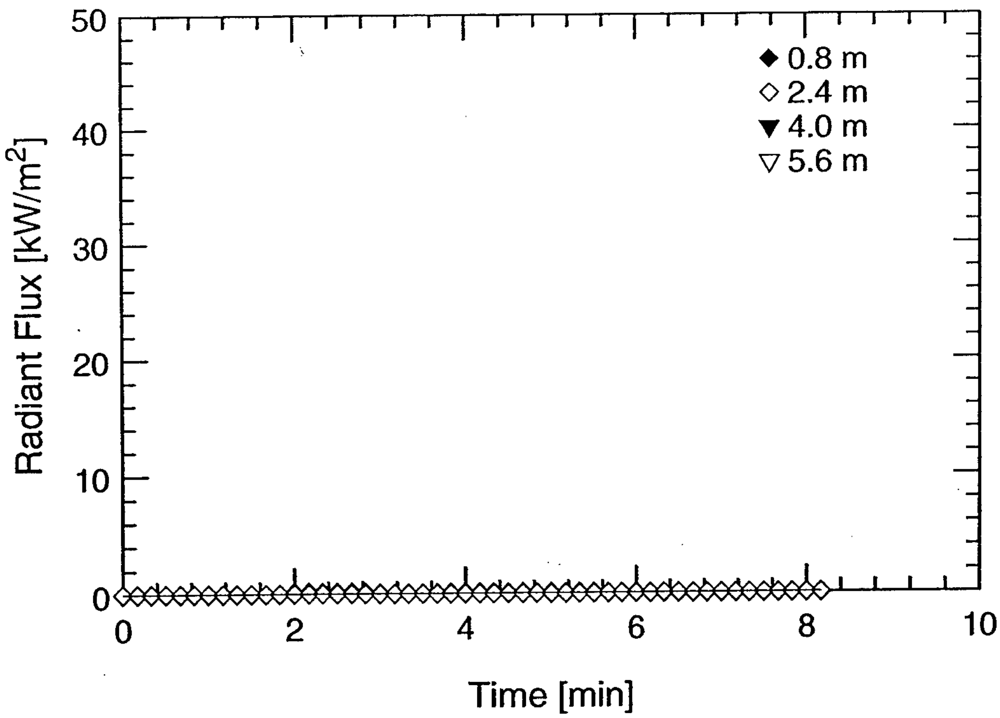


FR 36 - 0.5 m

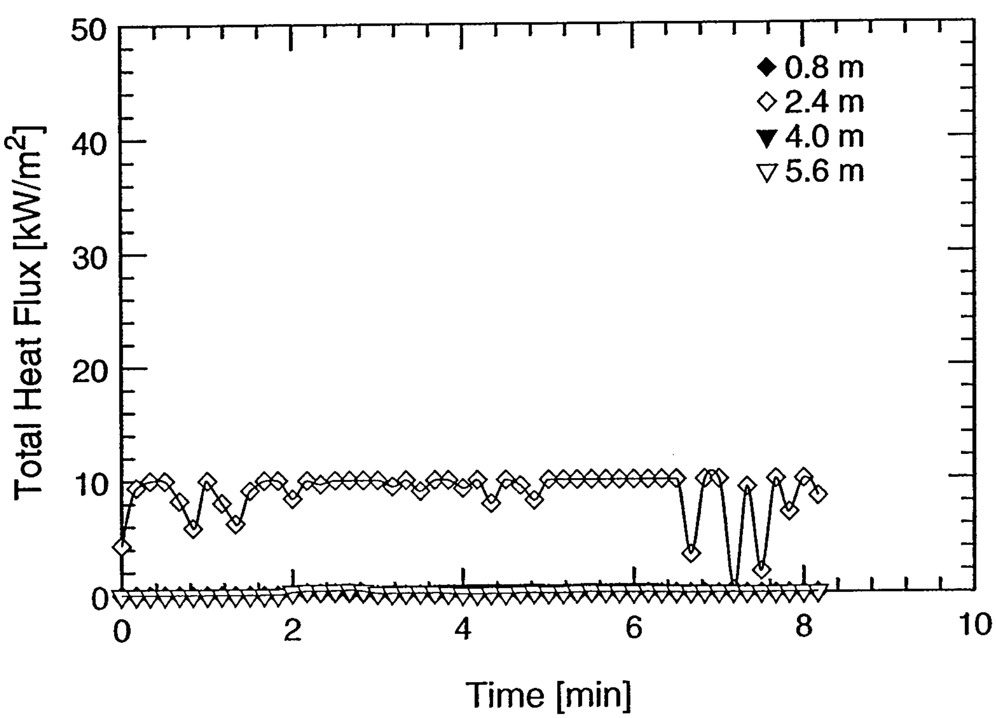


FR 36 - 4.5 m

Test #41

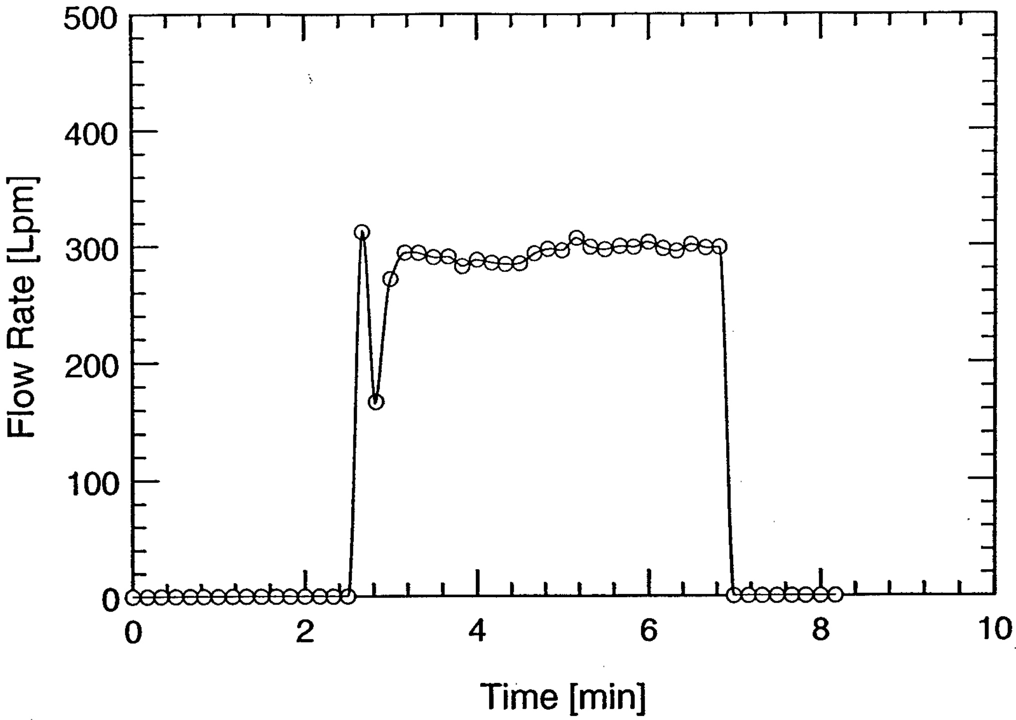


FR 22

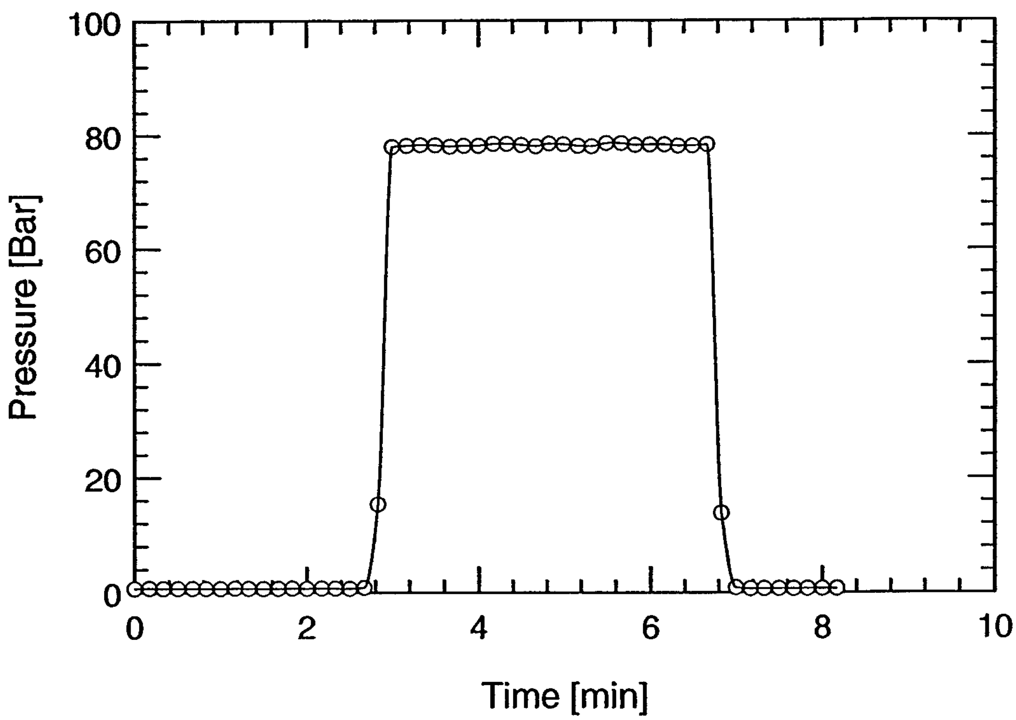


FR 22

Test #41

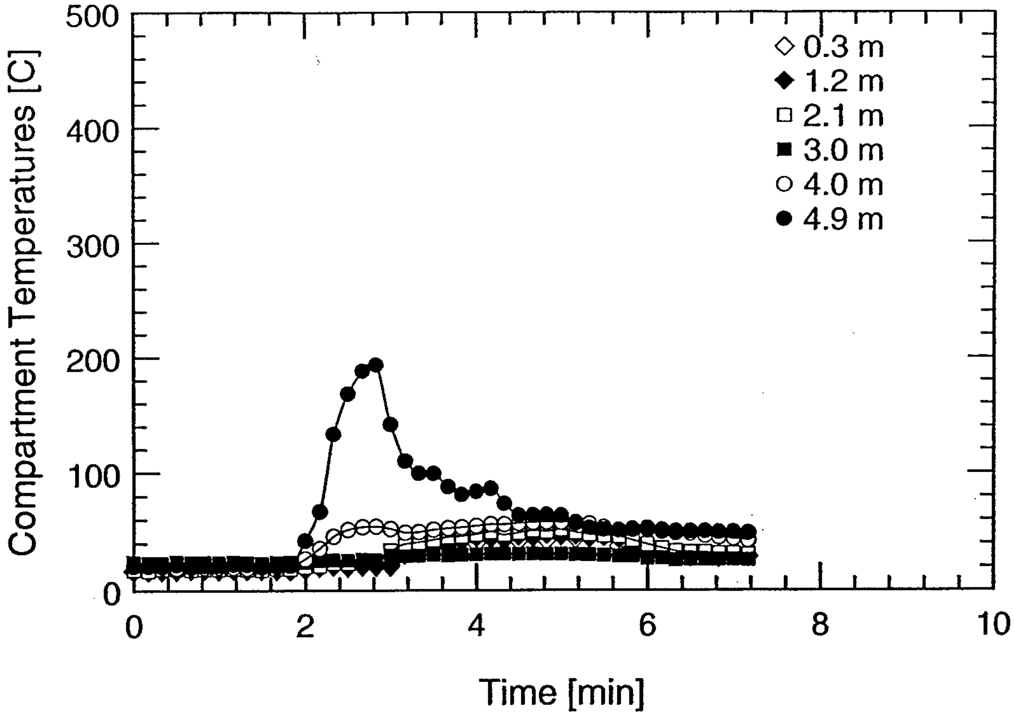


Water Mist System Flow Rate

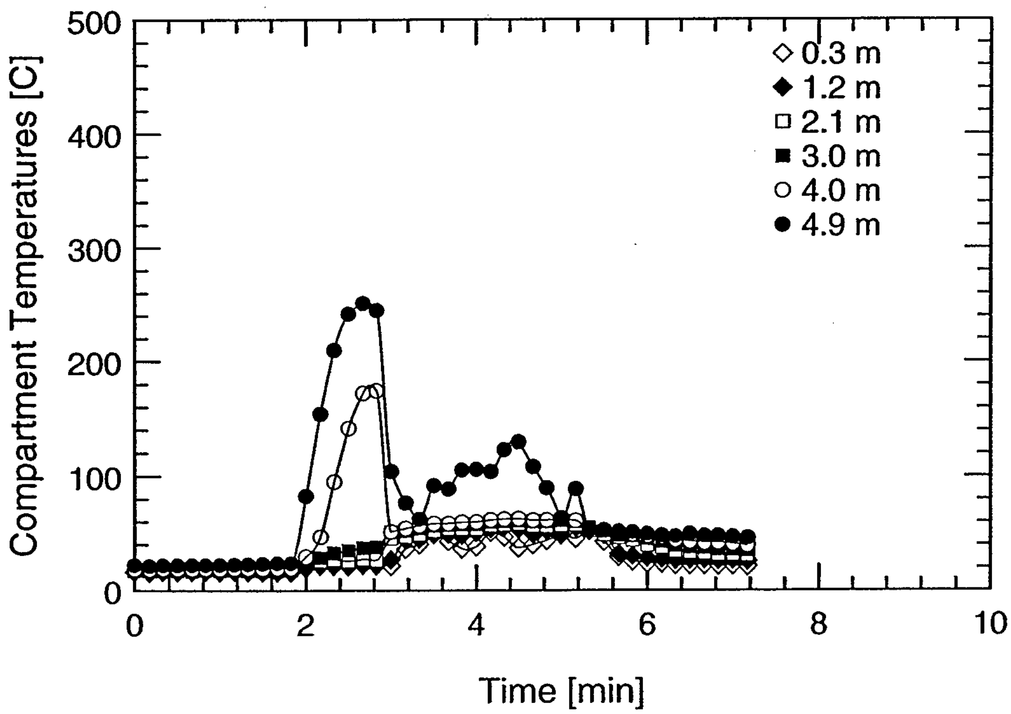


Water Mist System Pressure

Test #41

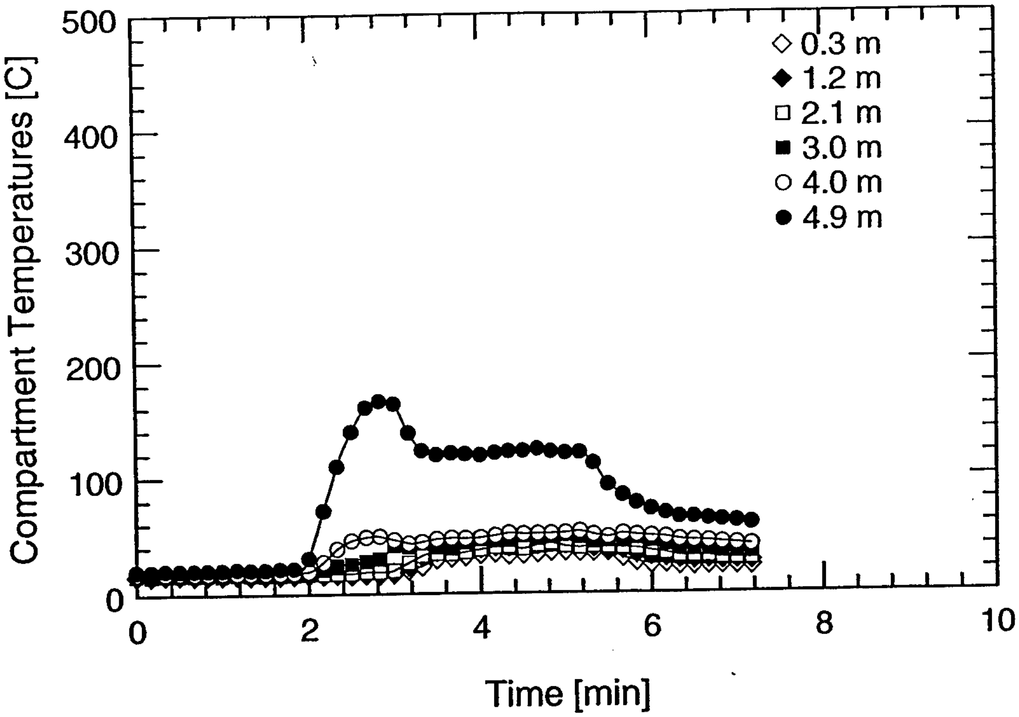


5-22-1

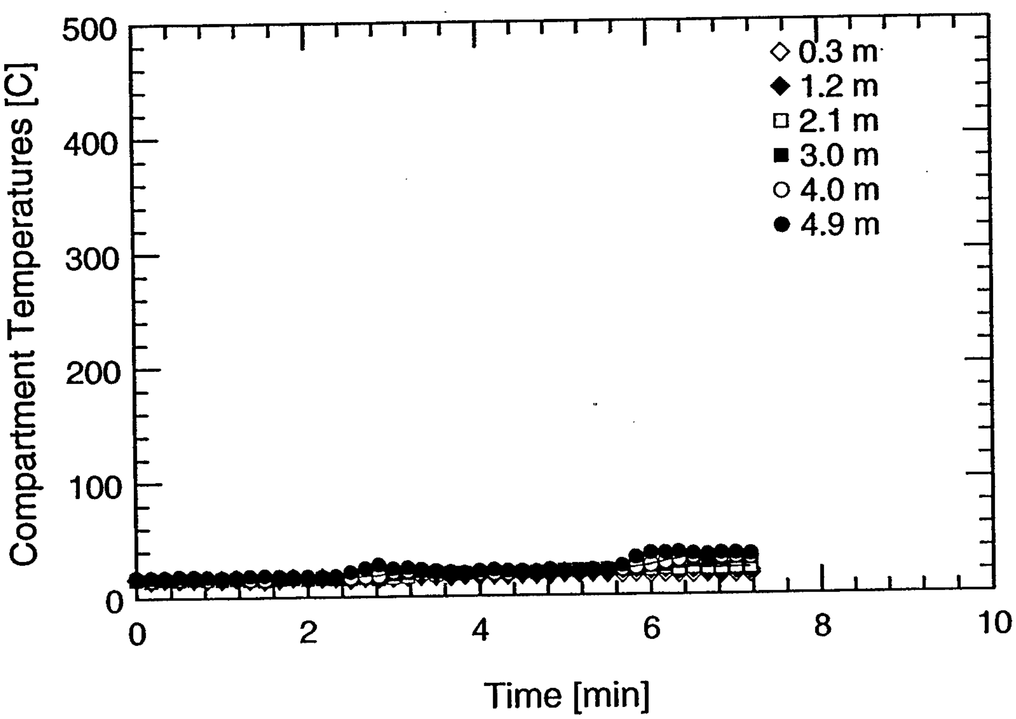


5-27-1

Test #42

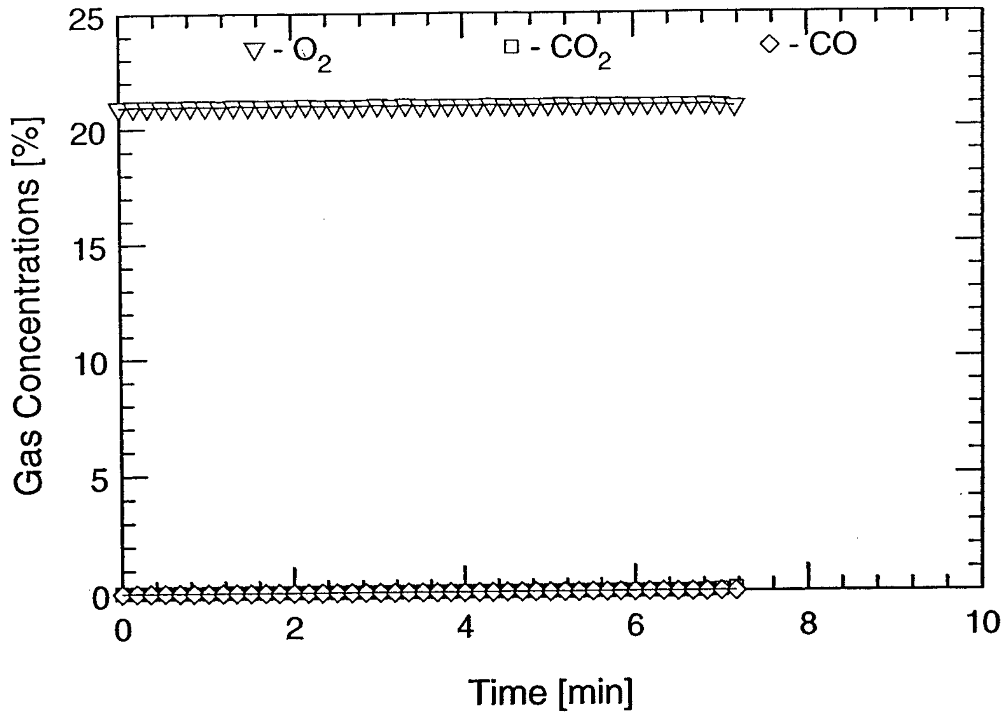


5-27-2

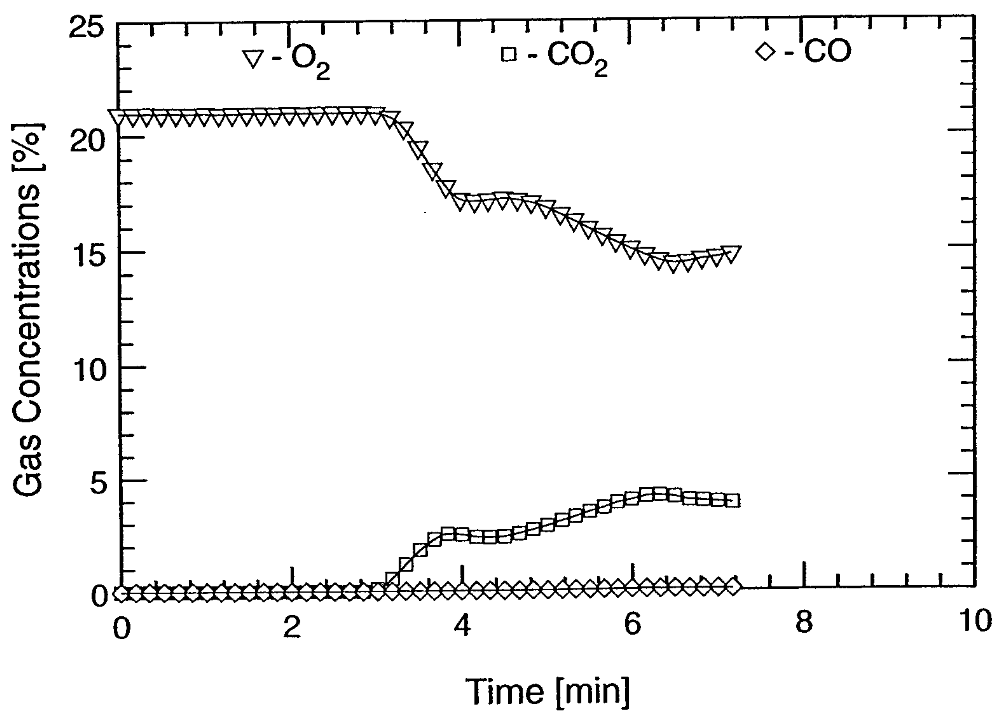


5-35-1

Test #42

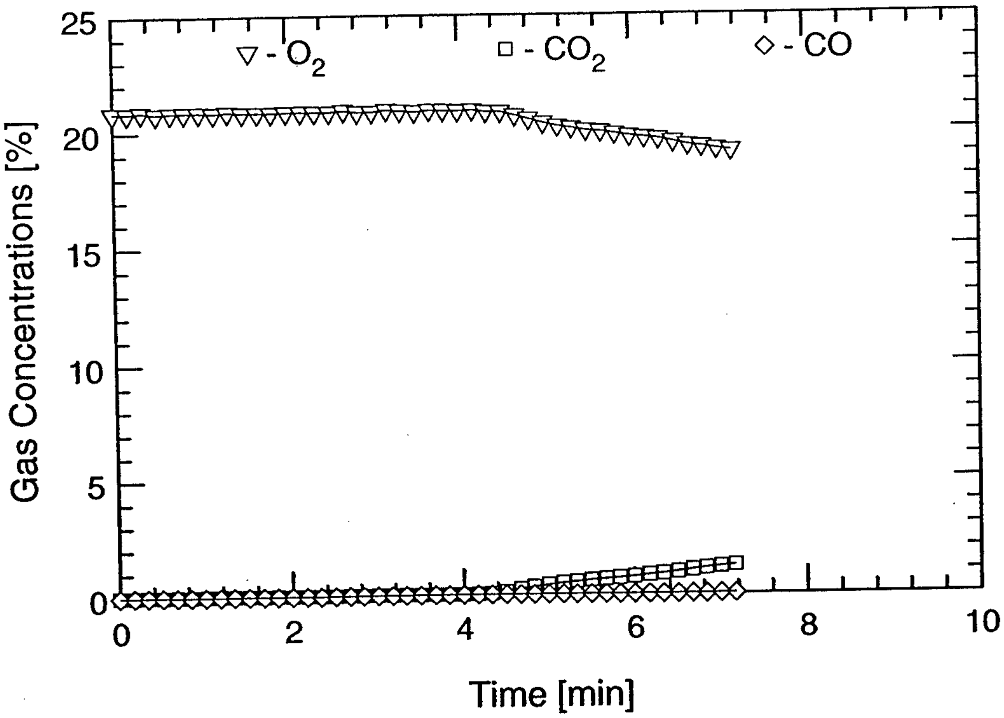


FR 22 - 0.5 m

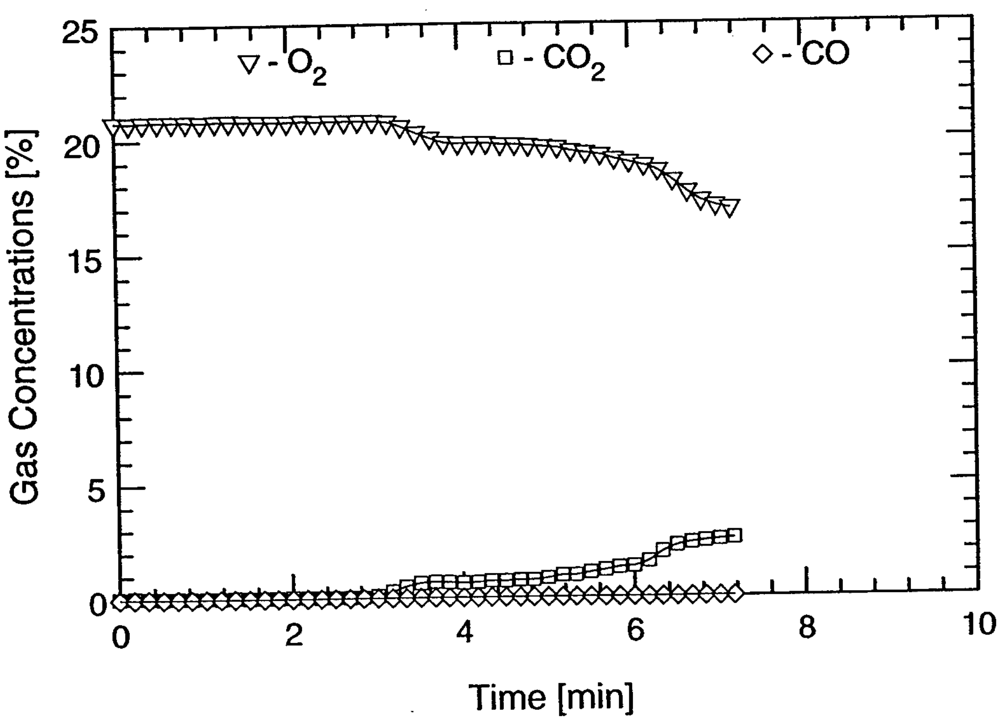


FR 22 - 4.5 m

Test #42

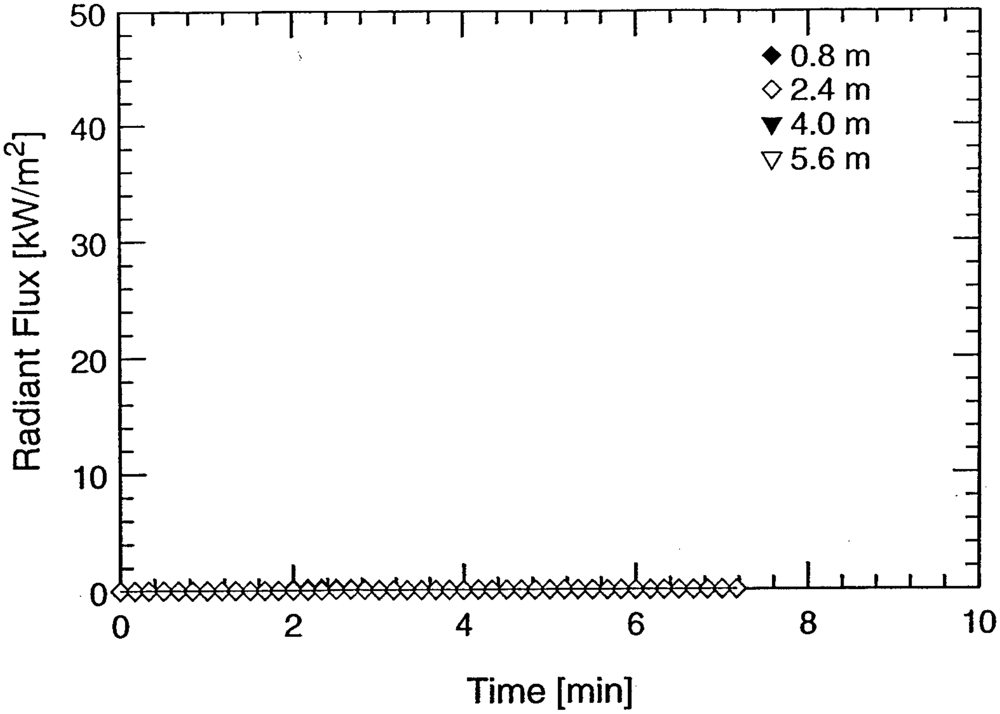


FR 36 - 0.5 m

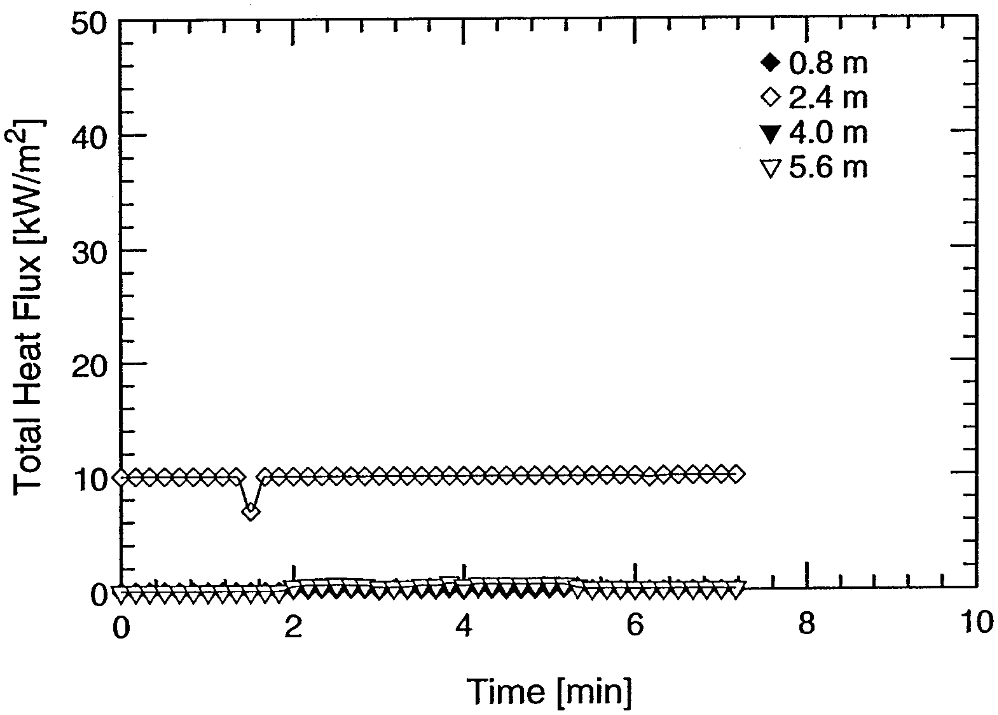


FR 36 - 4.5 m

Test #42

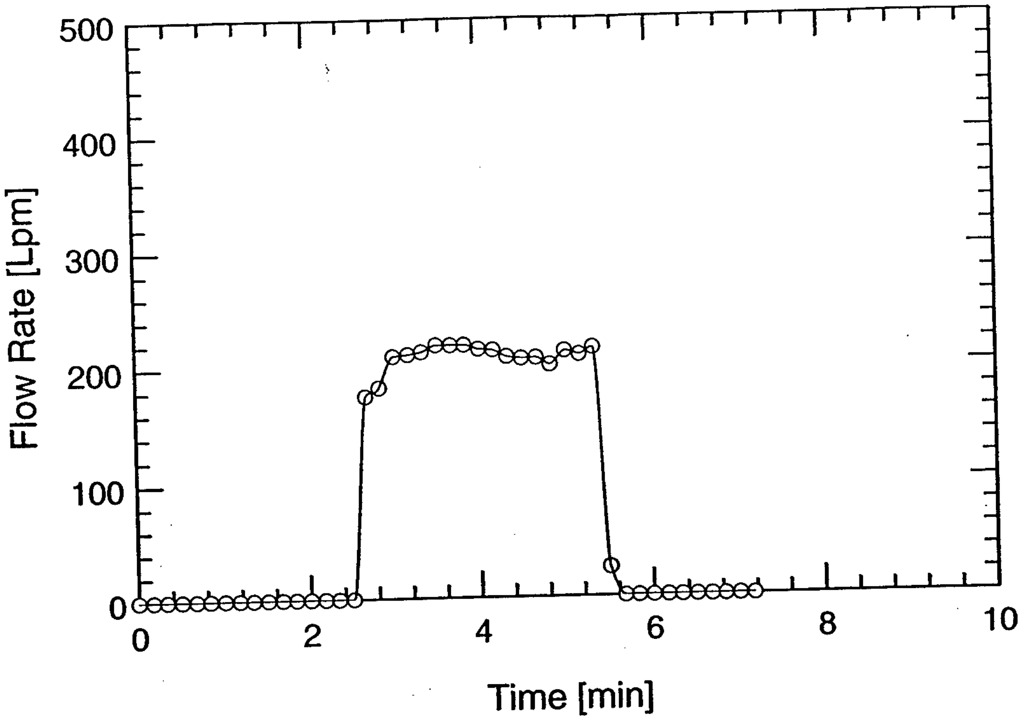


FR 22

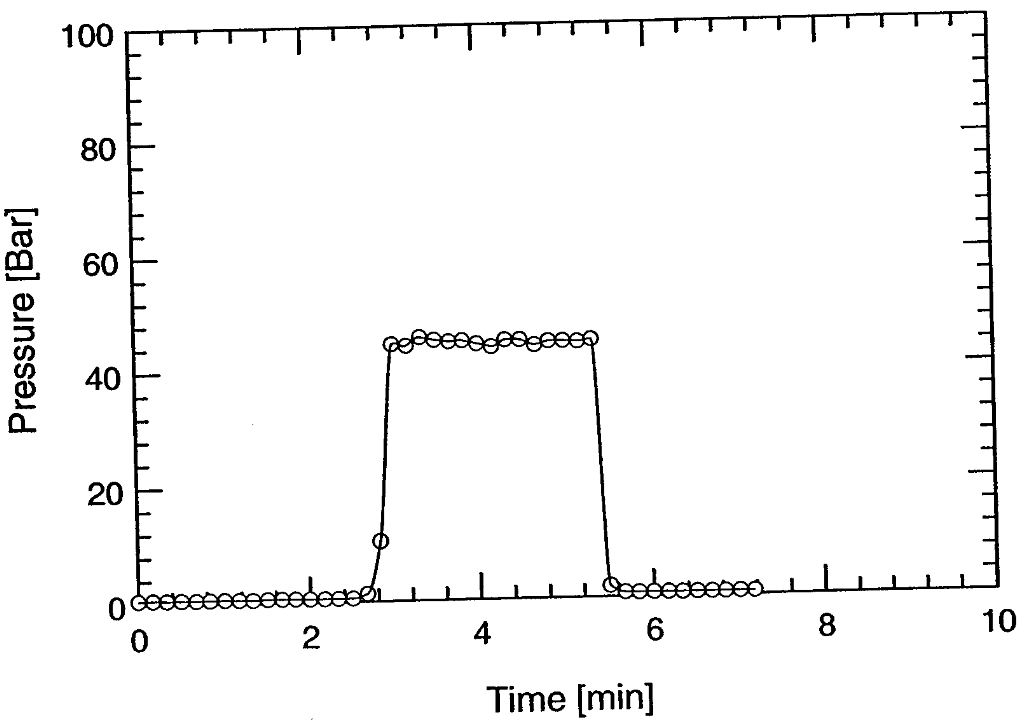


FR 22

Test #42

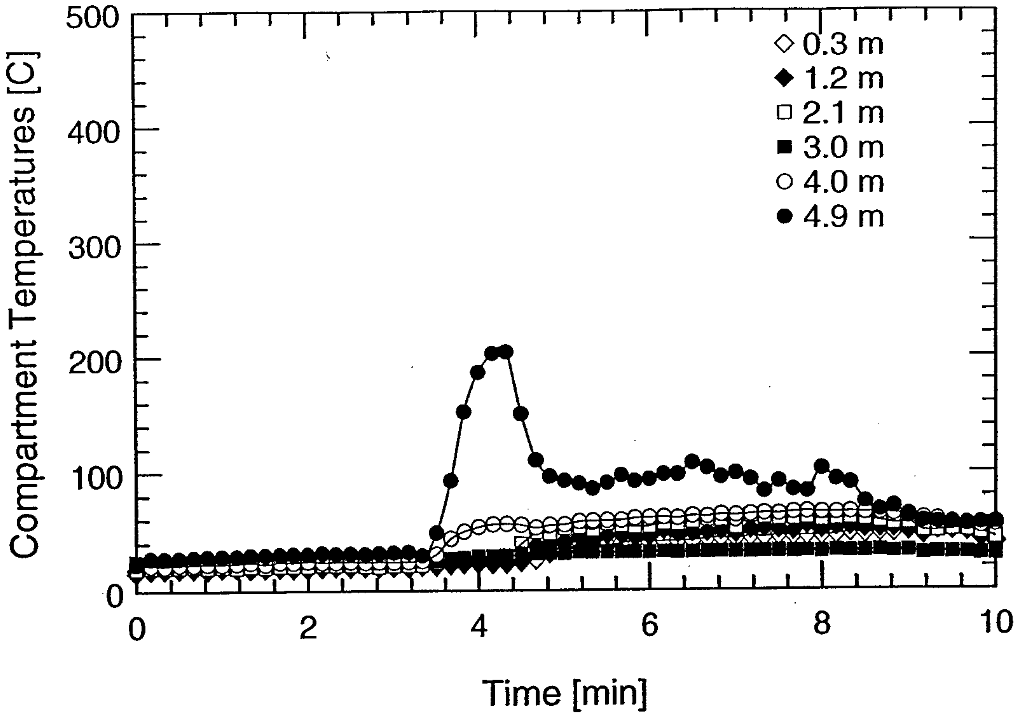


Water Mist System Flow Rate

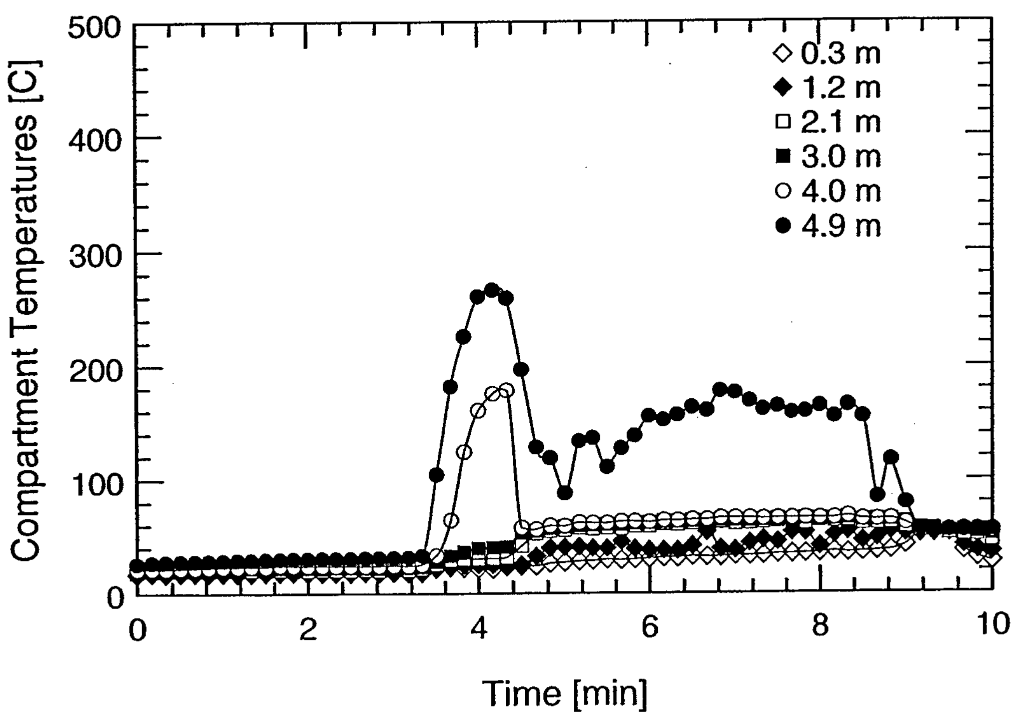


Water Mist System Pressure

Test #42

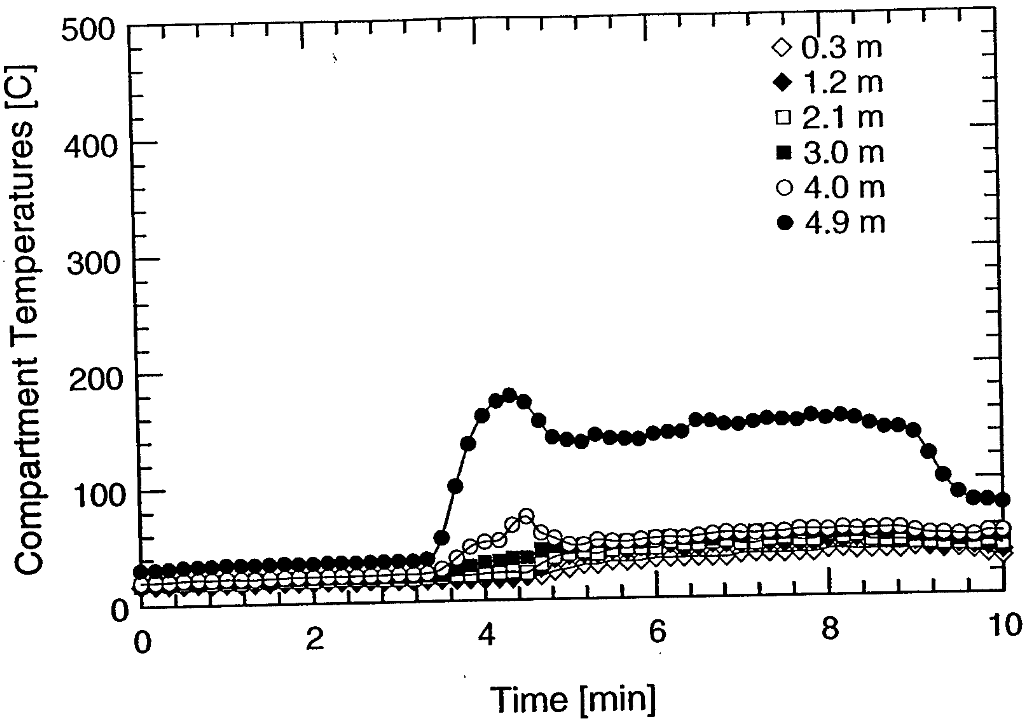


5-22-1

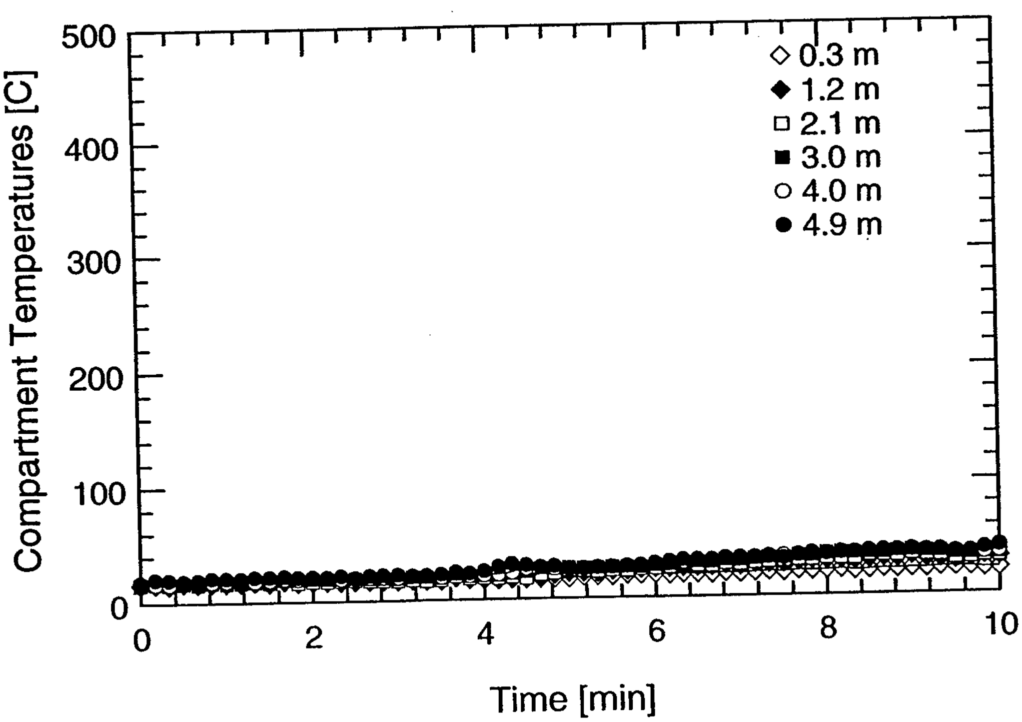


5-27-1

Test #43

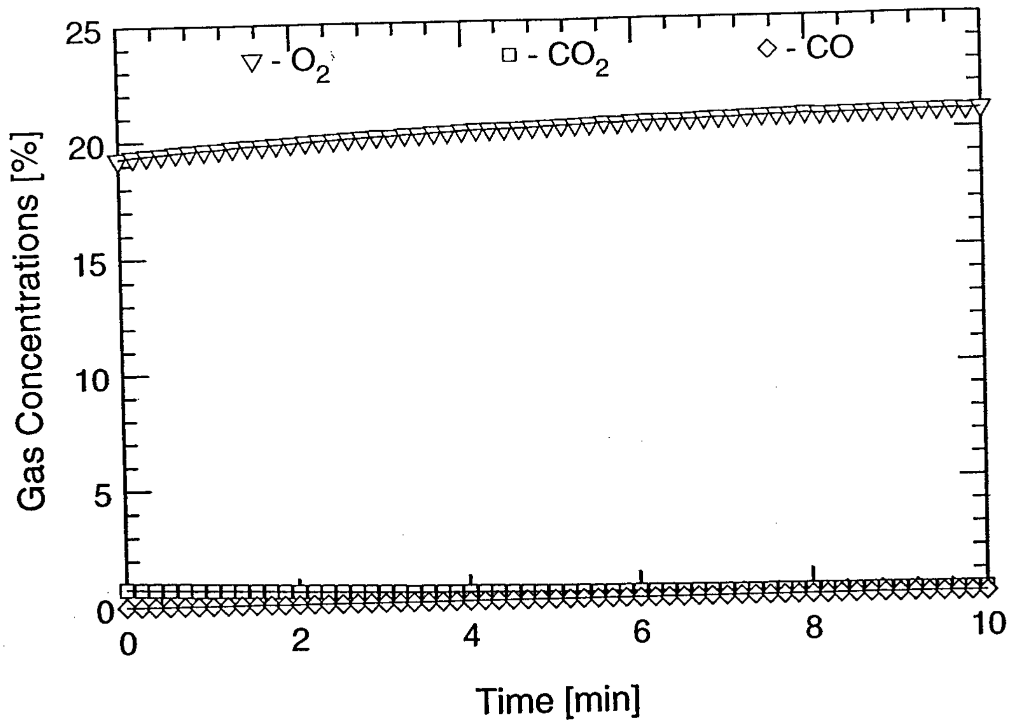


5-27-2

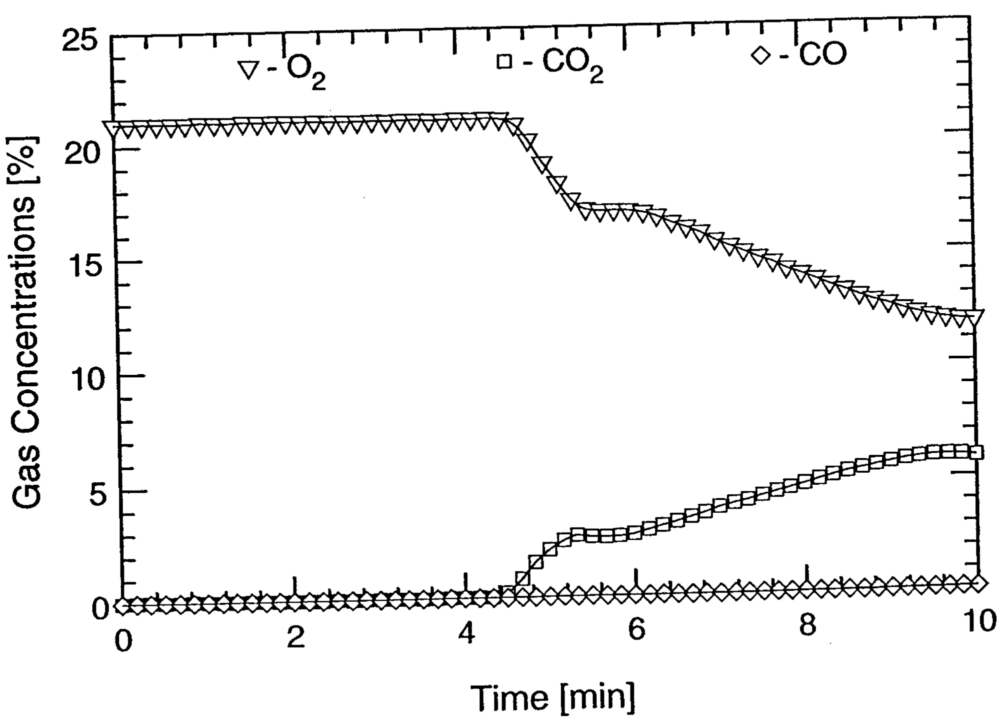


5-35-1

Test #43

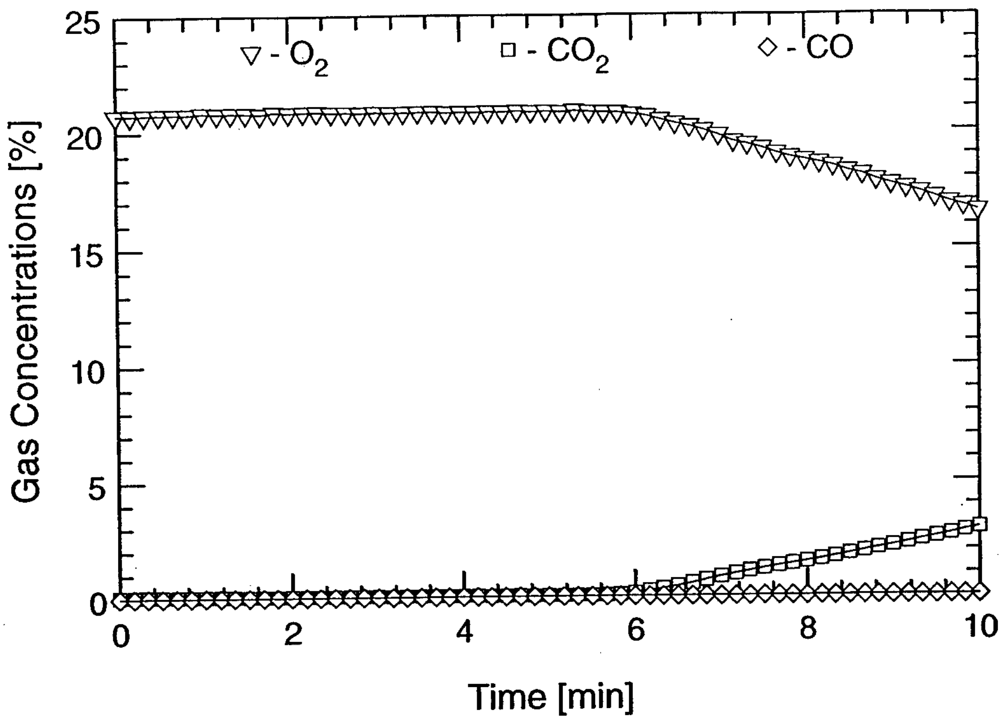


FR 22 - 0.5 m

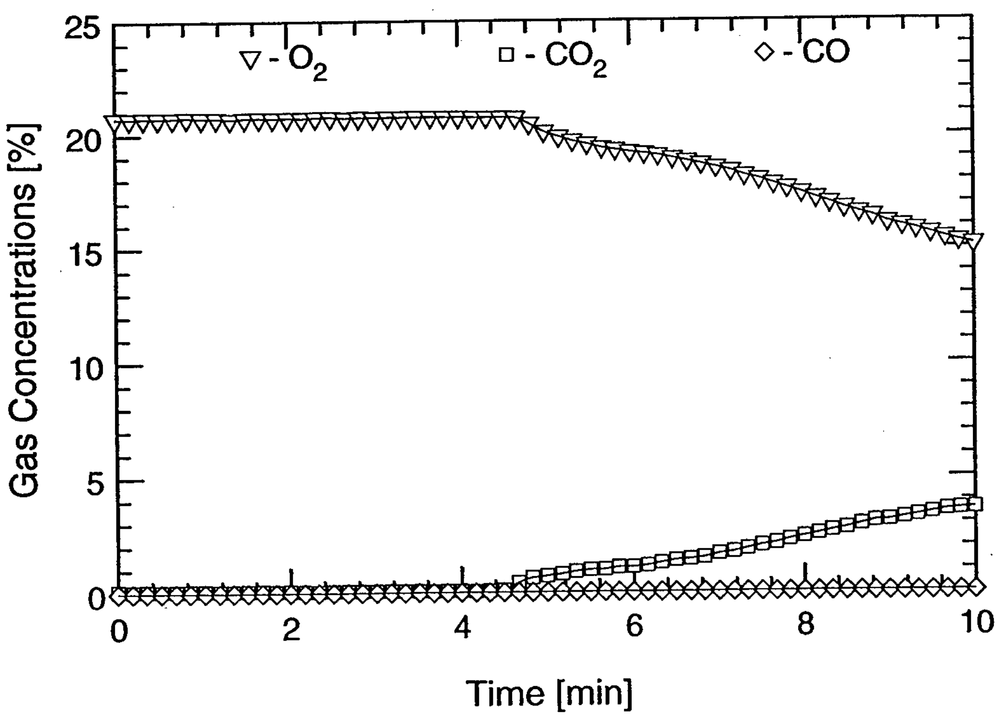


FR 22 - 4.5 m

Test #43

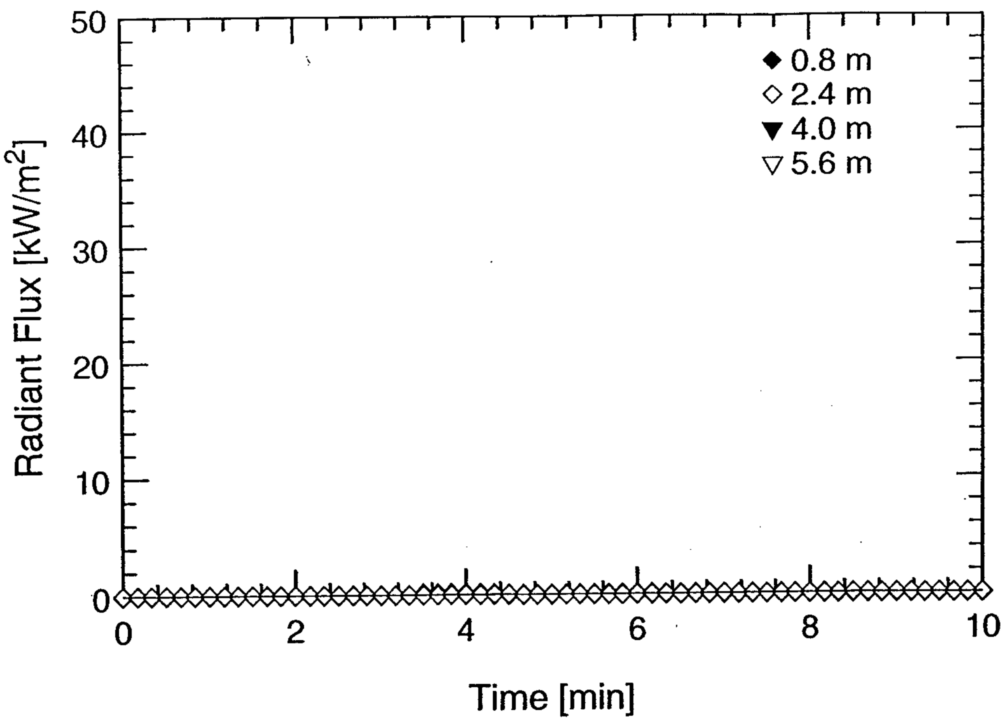


FR 36 - 0.5 m

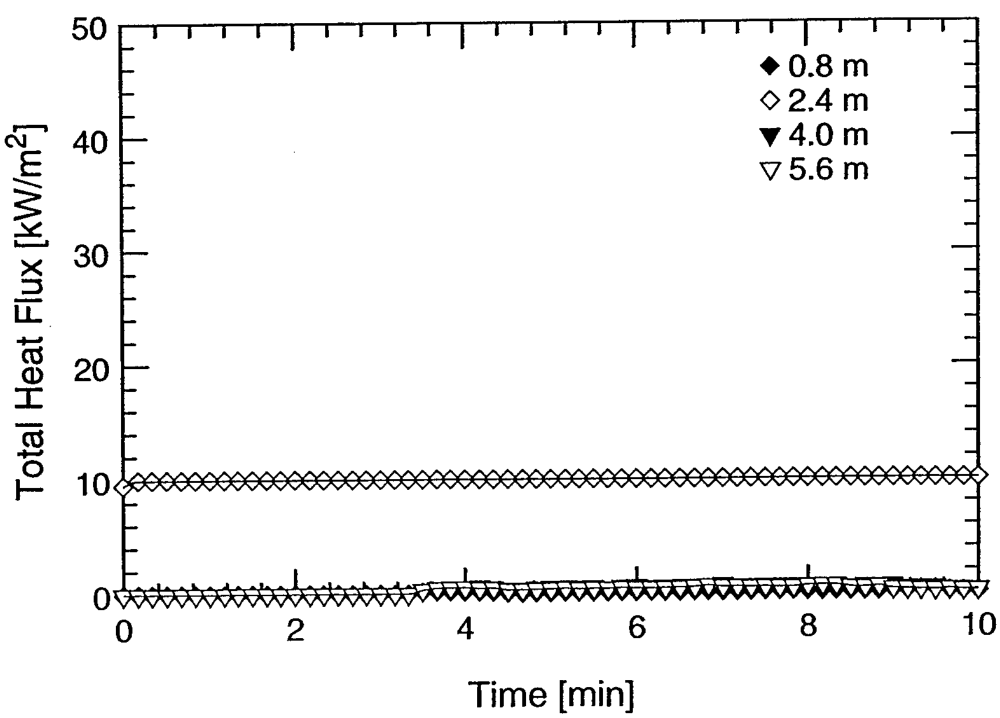


FR 36 - 4.5 m

Test #43

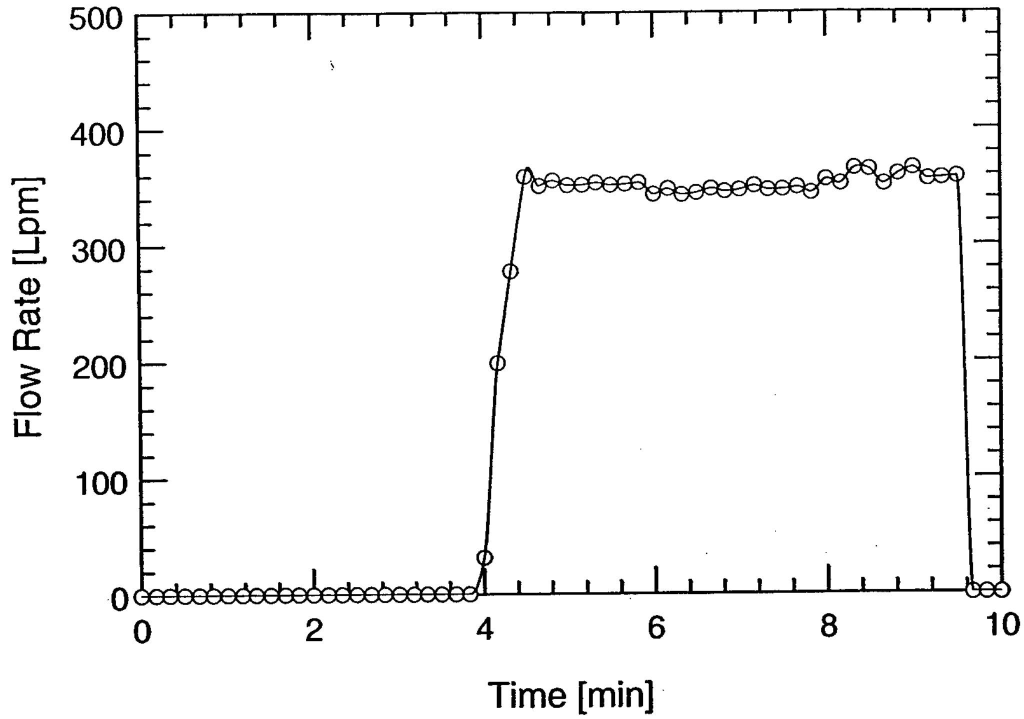


FR 22

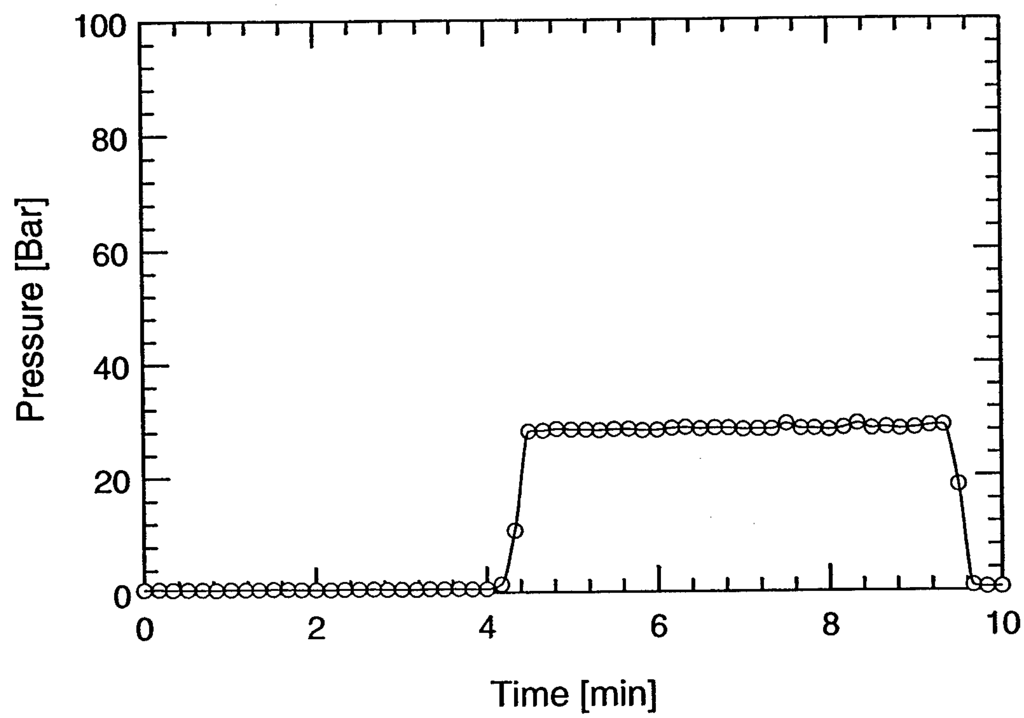


FR 22

Test #43

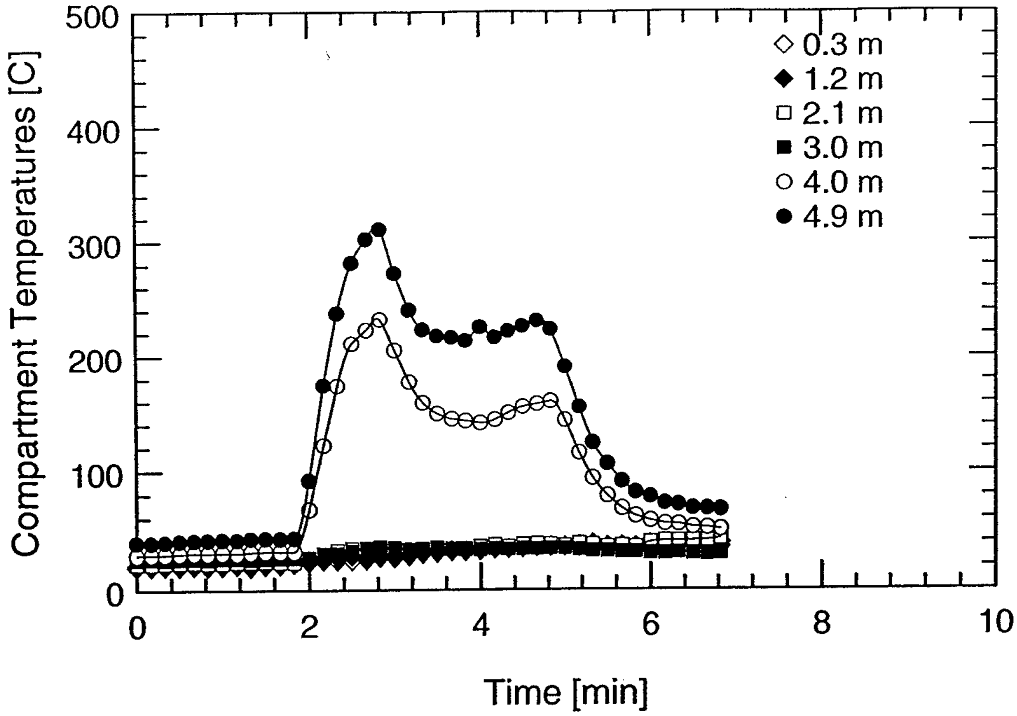


Water Mist System Flow Rate

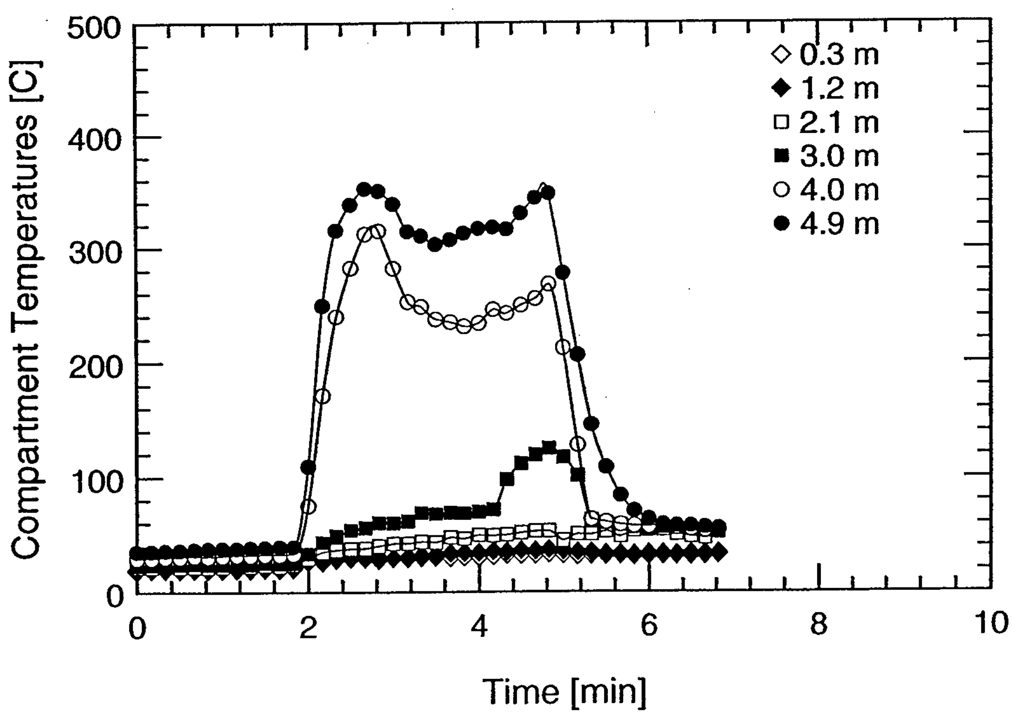


Water Mist System Pressure

Test #43

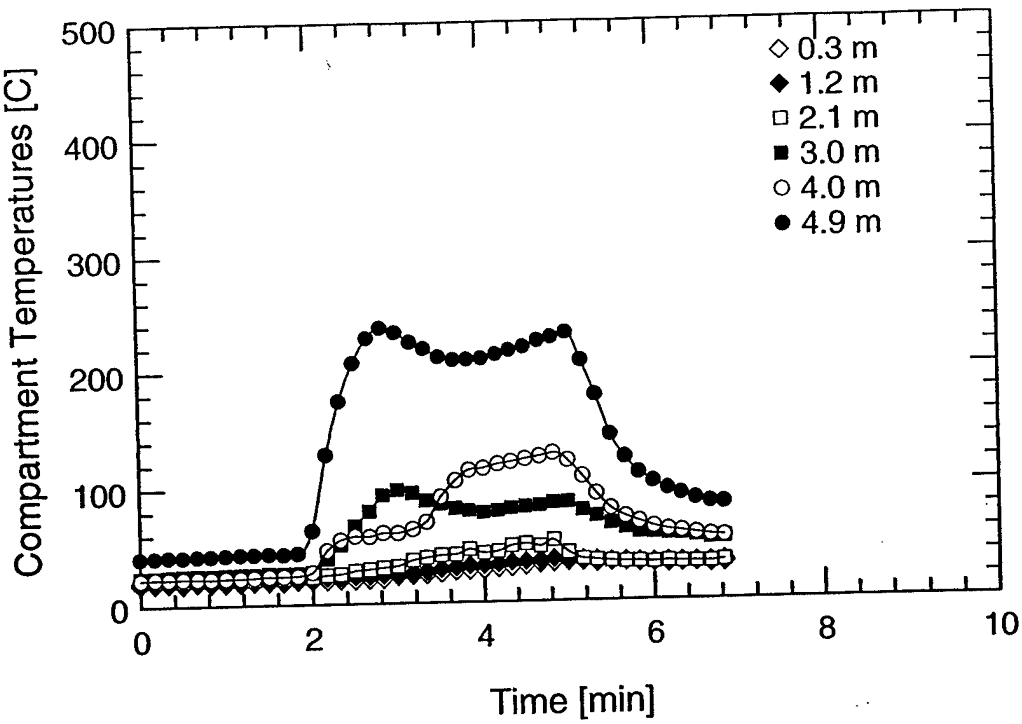


5-22-1

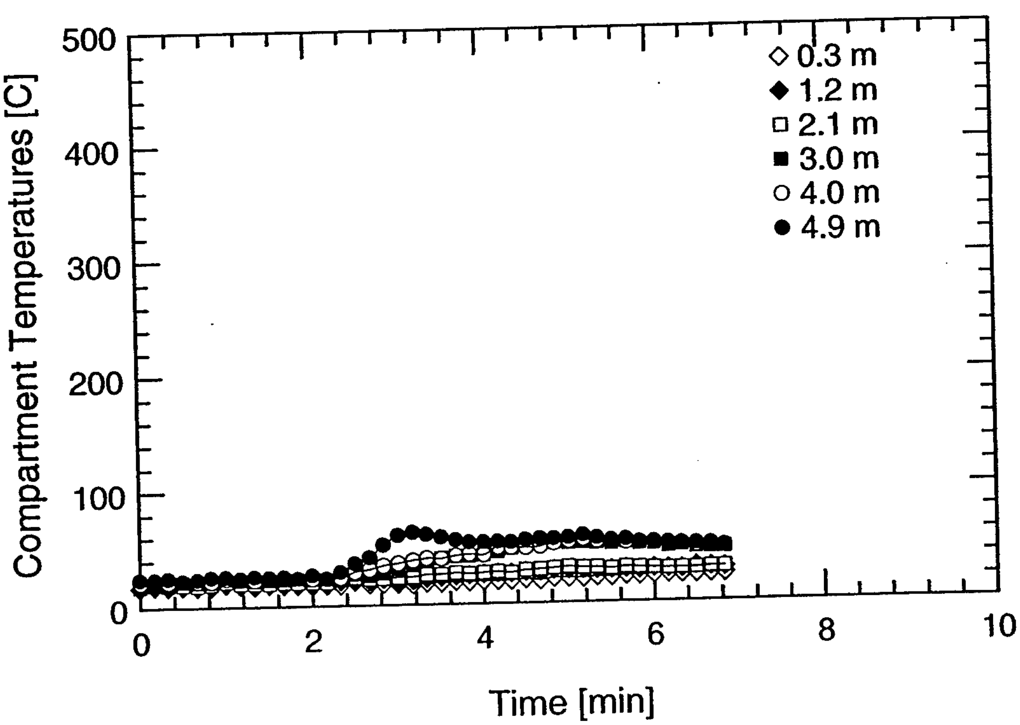


5-27-1

Test #44

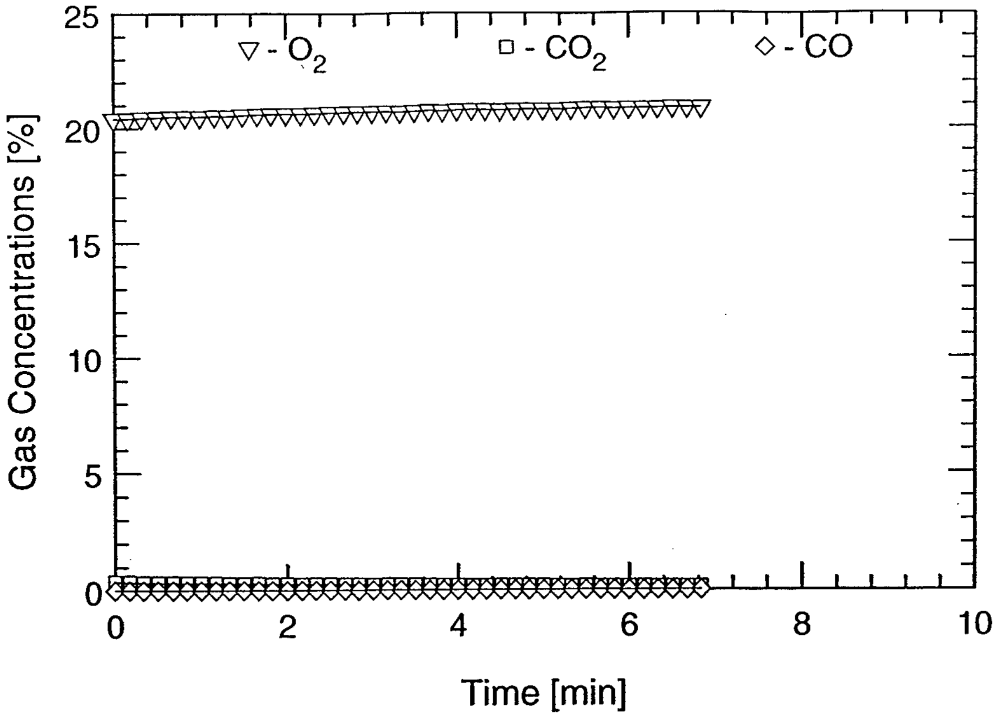


5-27-2

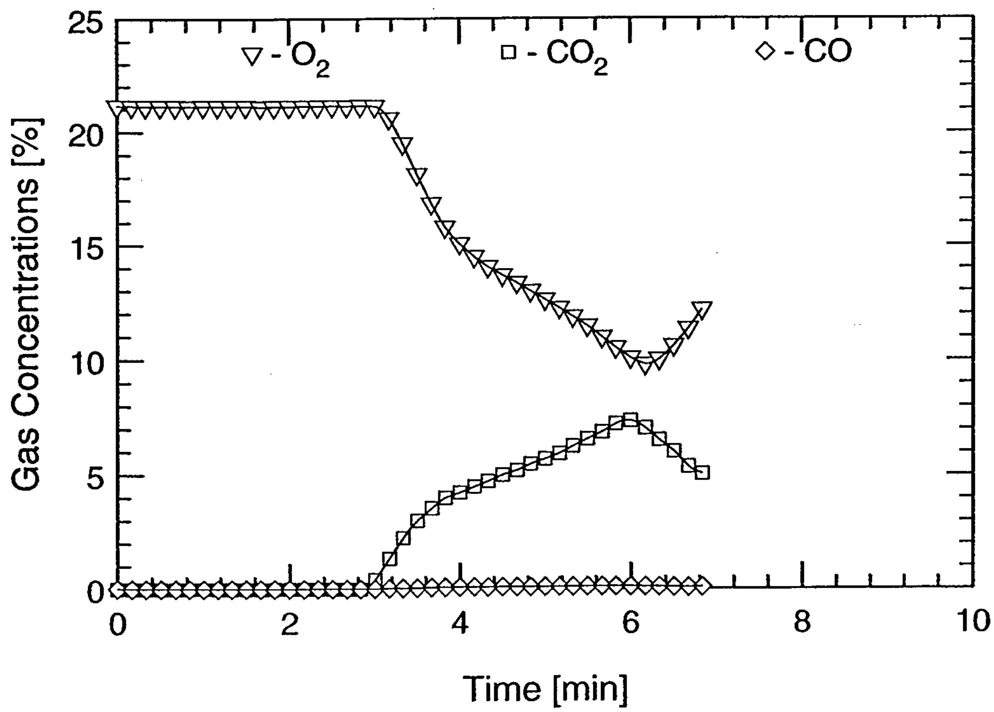


5-35-1

Test #44

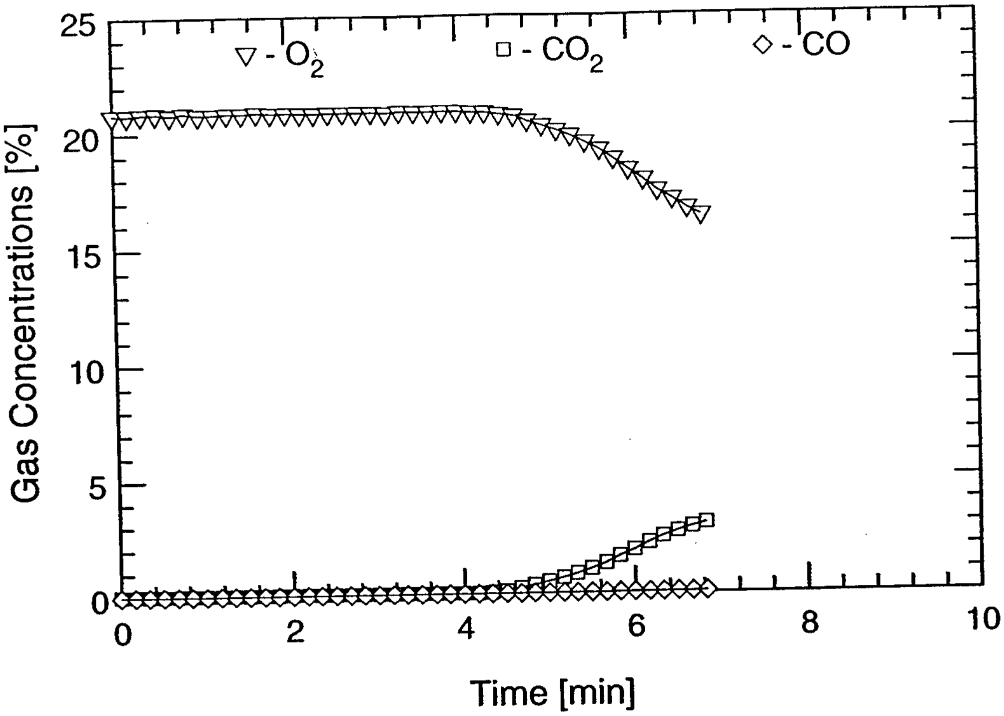


FR 22 - 0.5 m

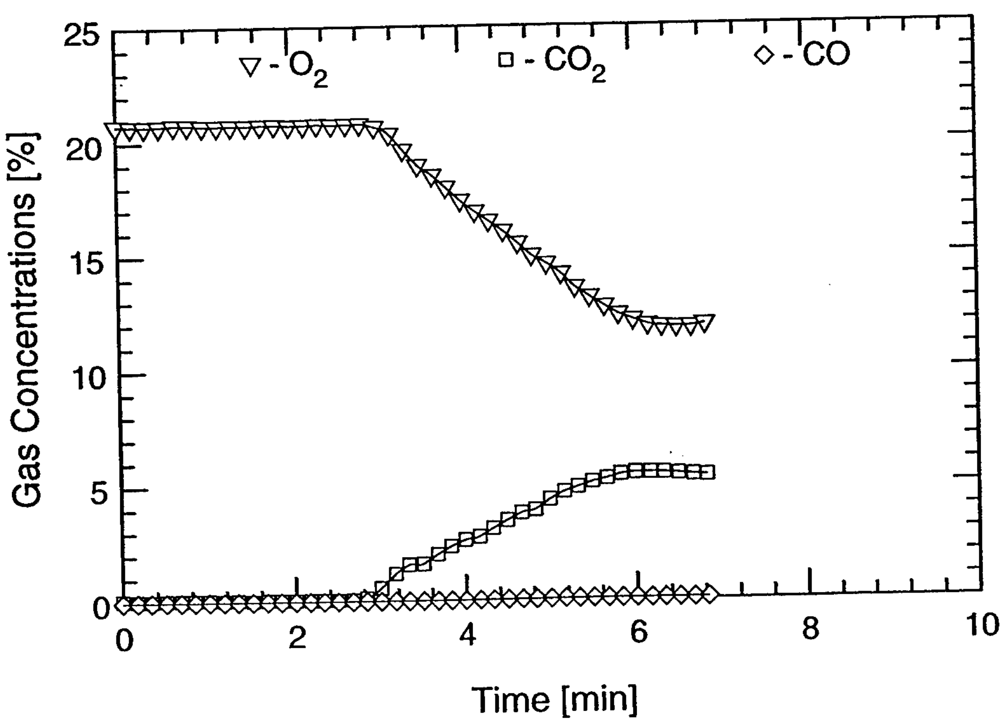


FR 22 - 4.5 m

Test #44

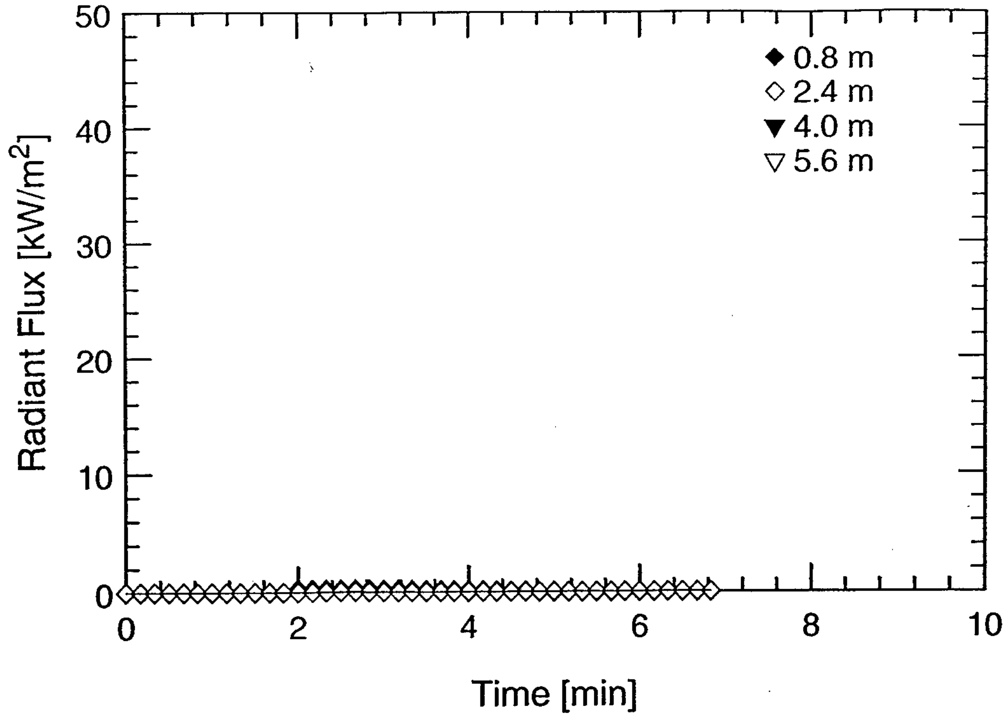


FR 36 - 0.5 m

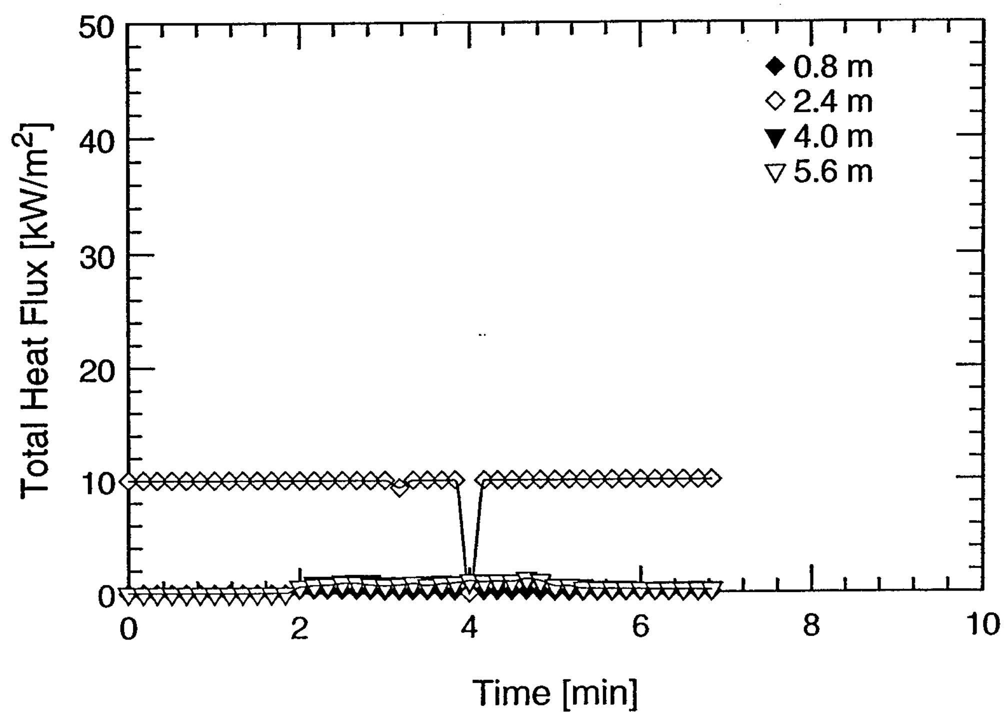


FR 36 - 4.5 m

Test #44

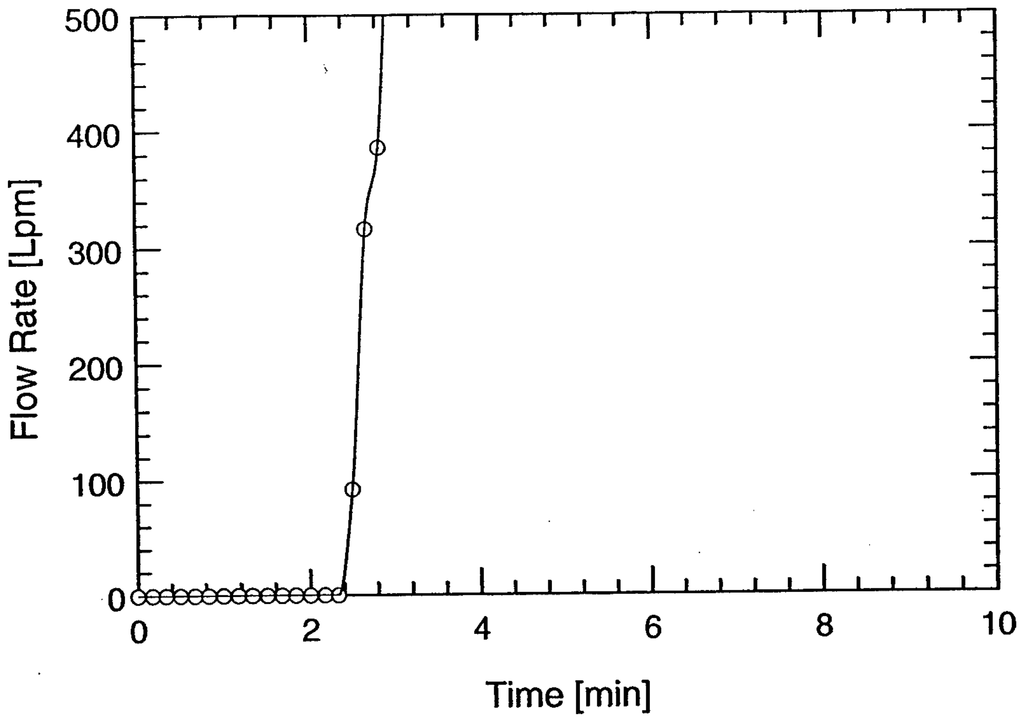


FR 22

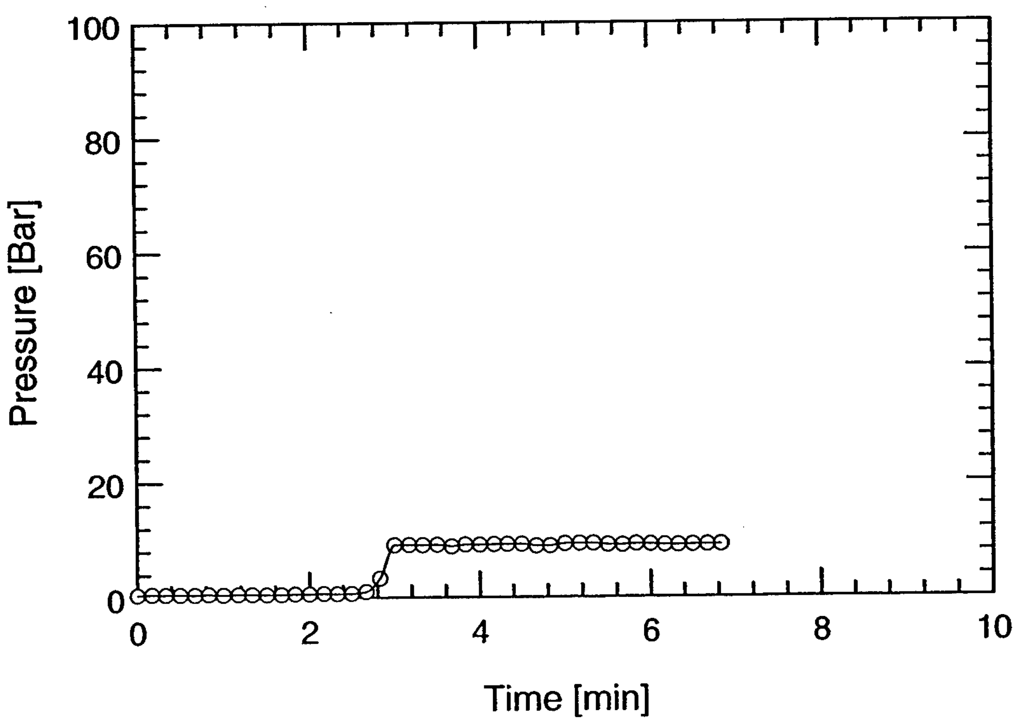


FR 22

Test #44

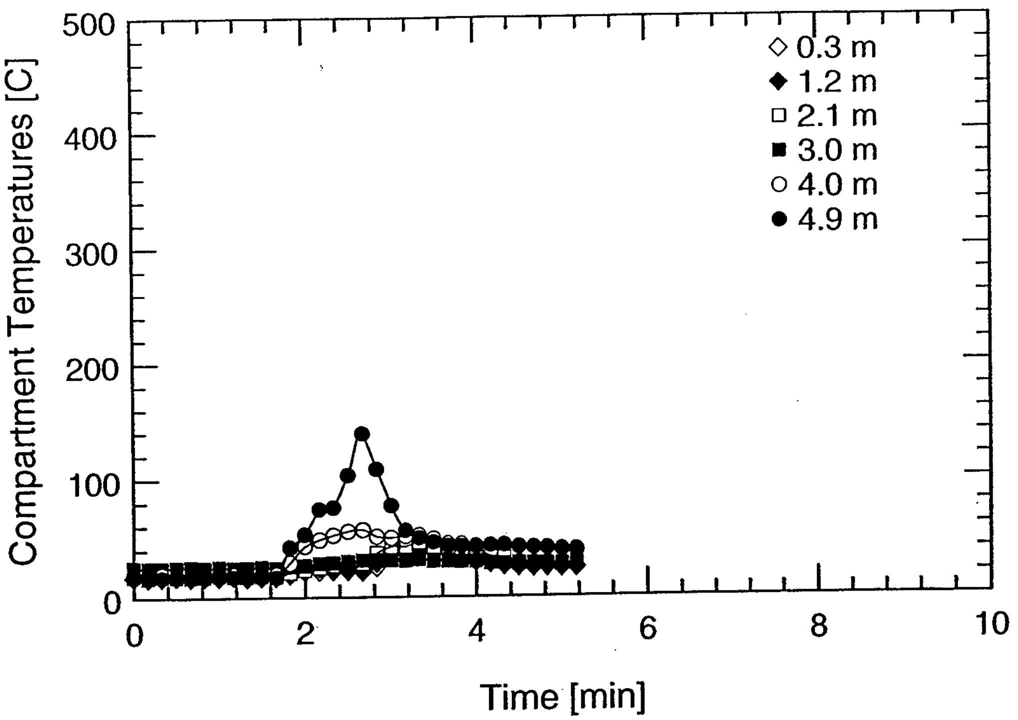


Water Mist System Flow Rate

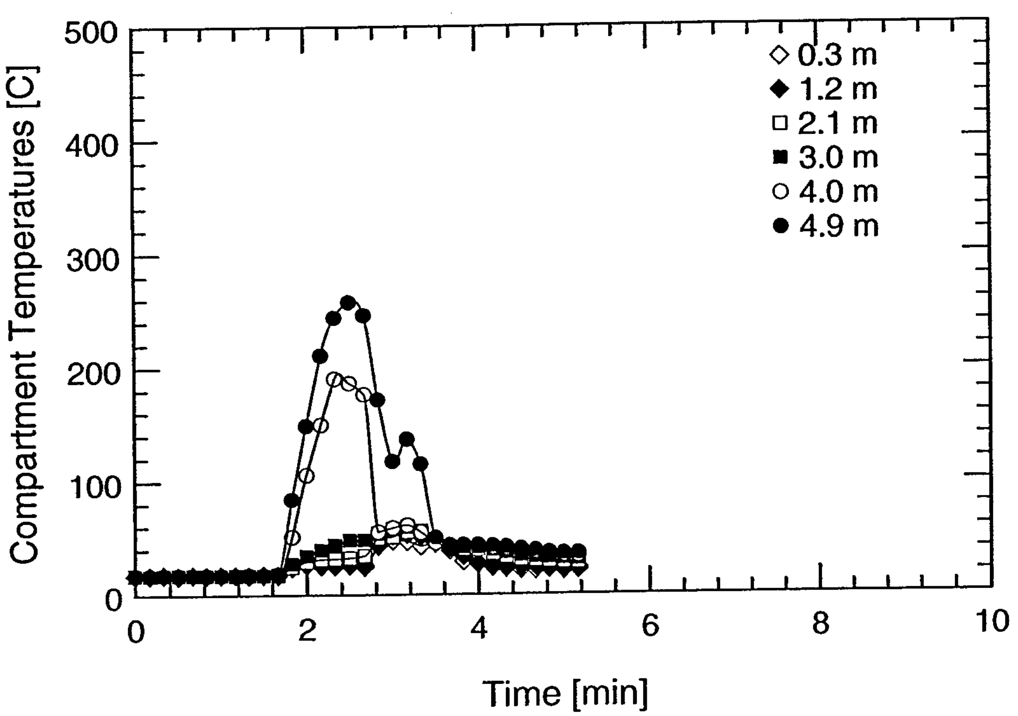


Water Mist System Pressure

Test #44

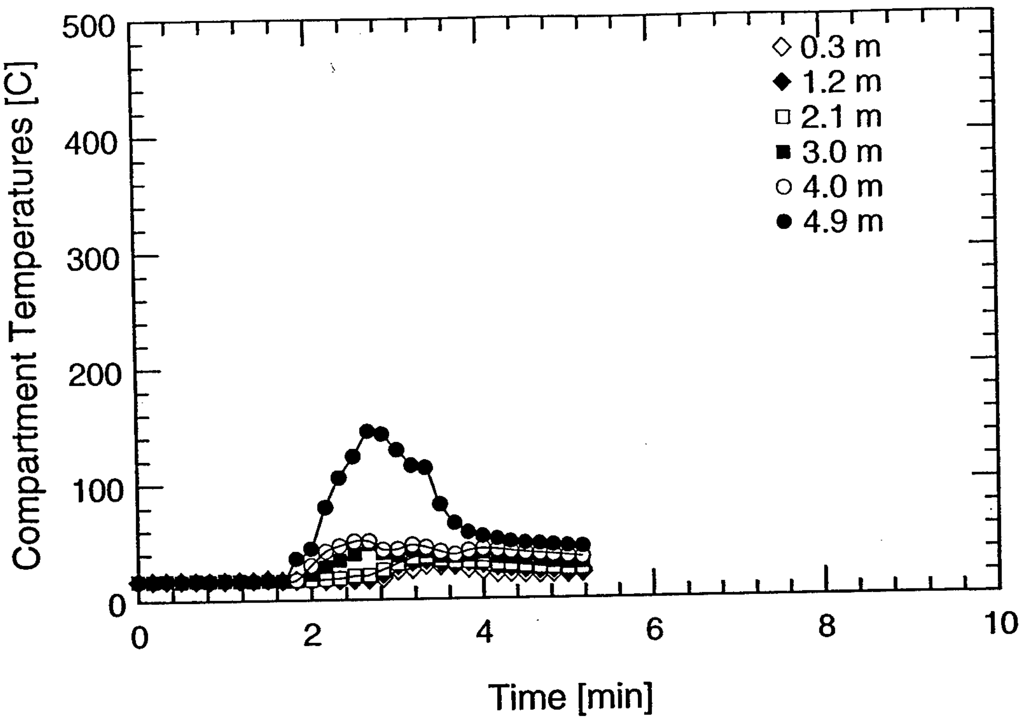


5-22-1

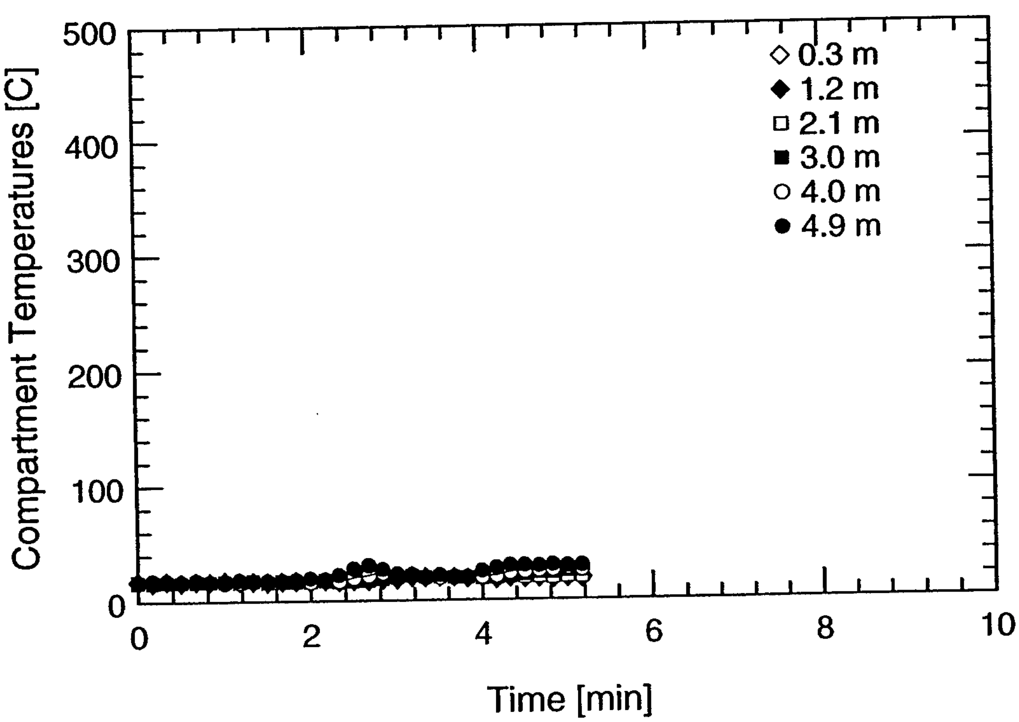


5-27-1

Test #45

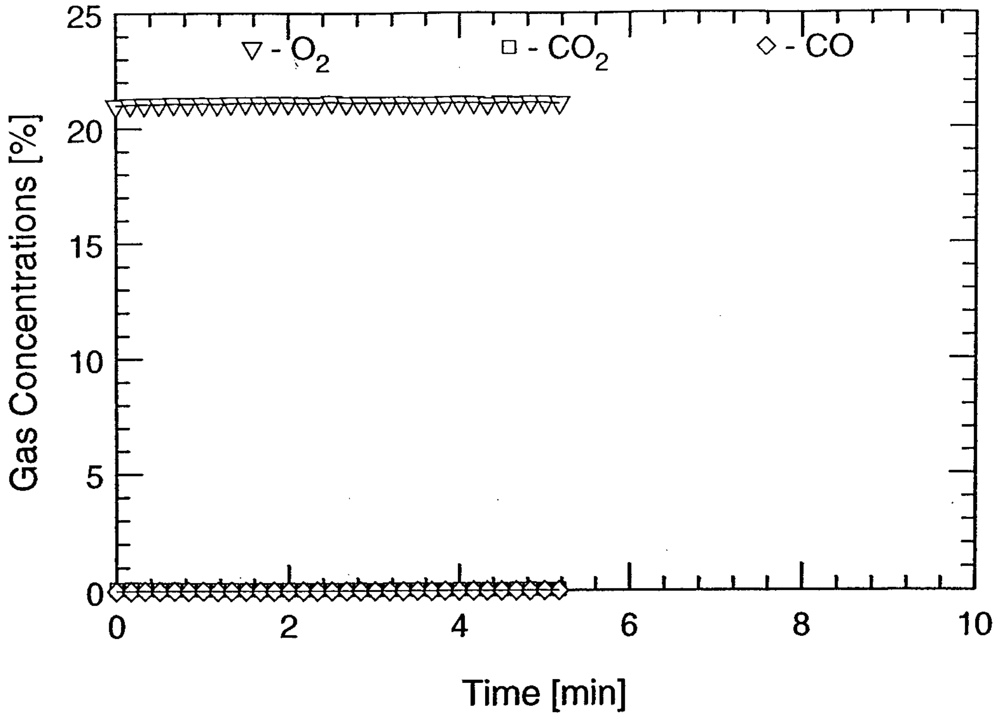


5-27-2

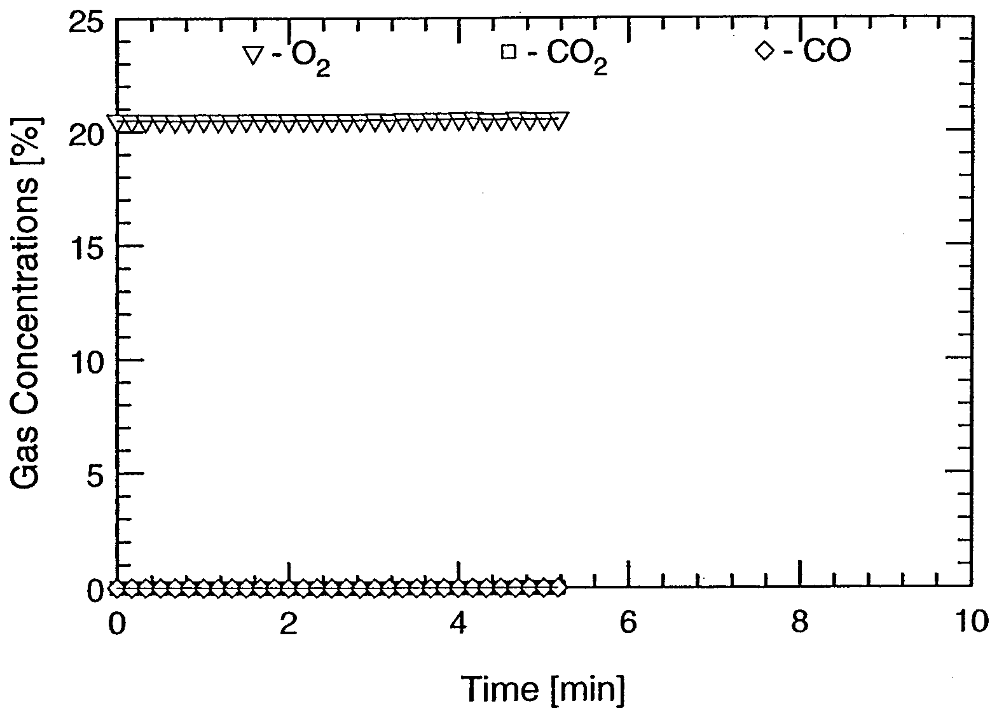


5-35-1

Test #45

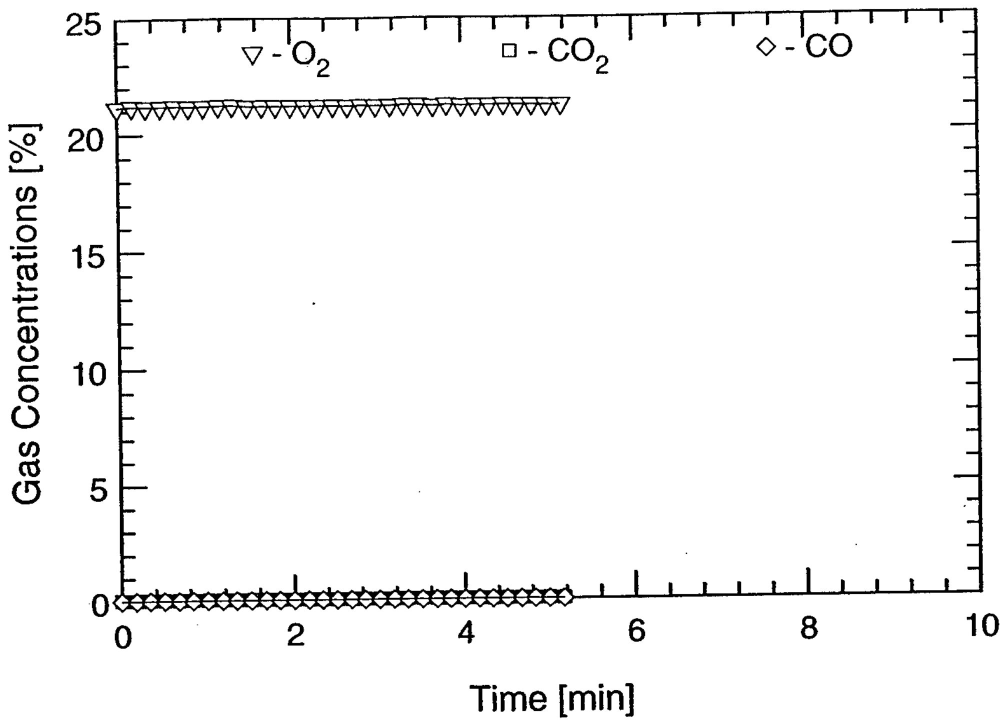


FR 22 - 0.5 m

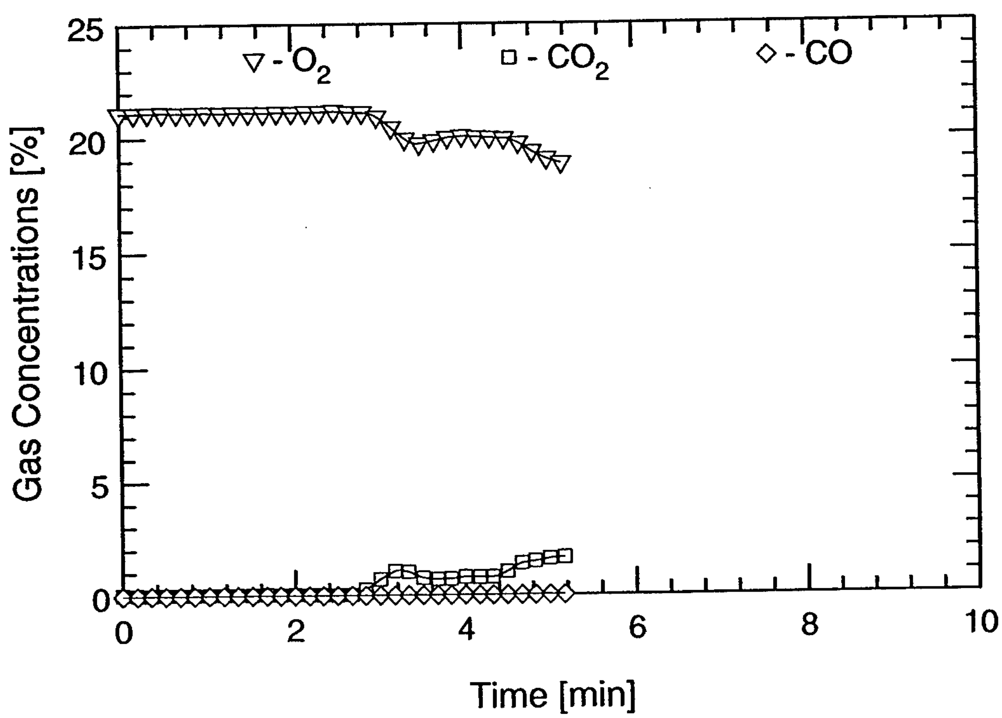


FR 22 - 4.5 m

Test #45

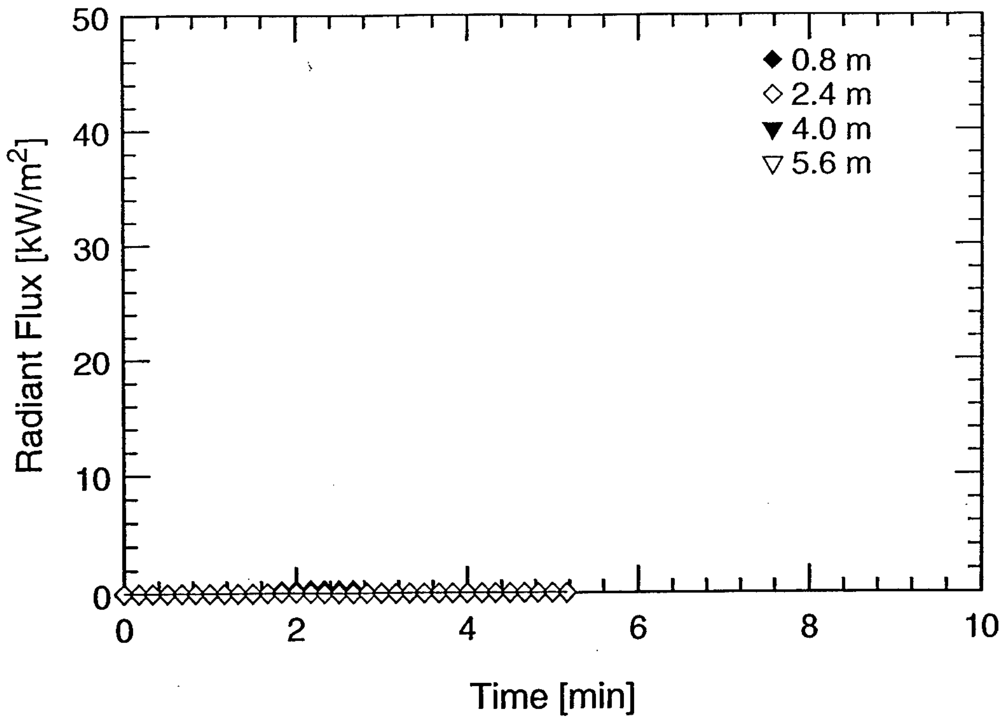


FR 36 - 0.5 m

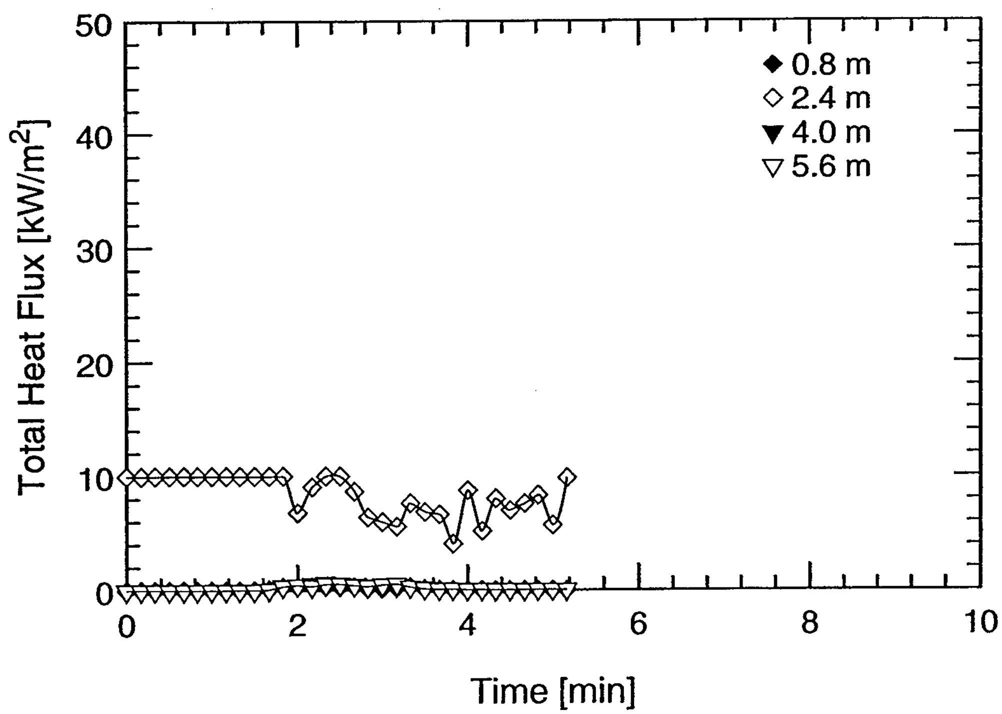


FR 36 - 4.5 m

Test #45

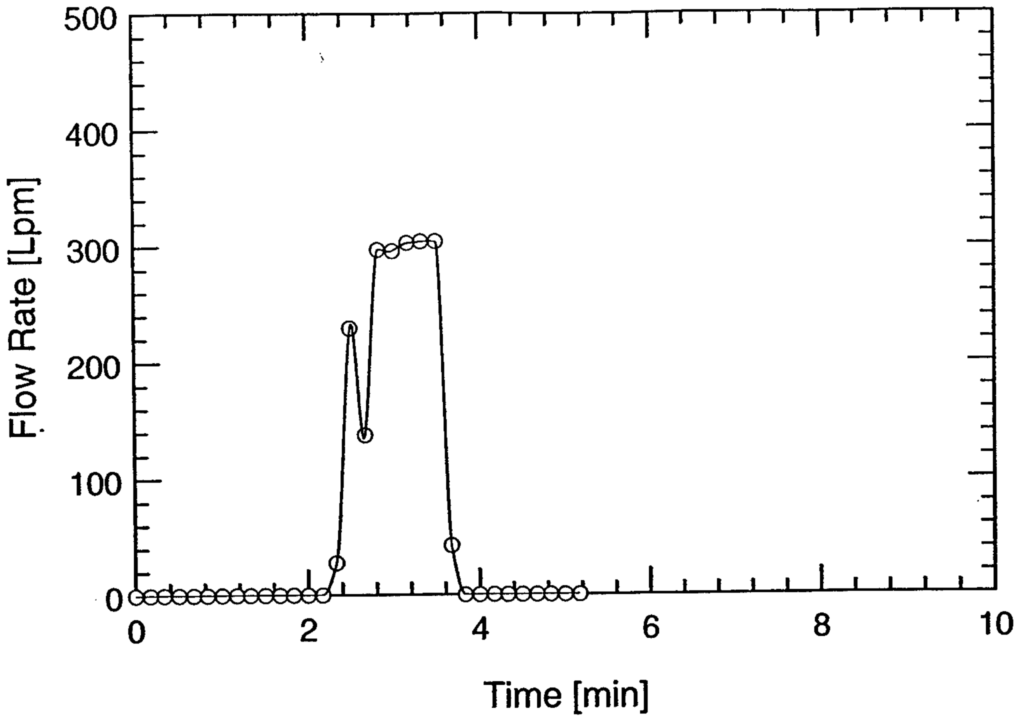


FR 22

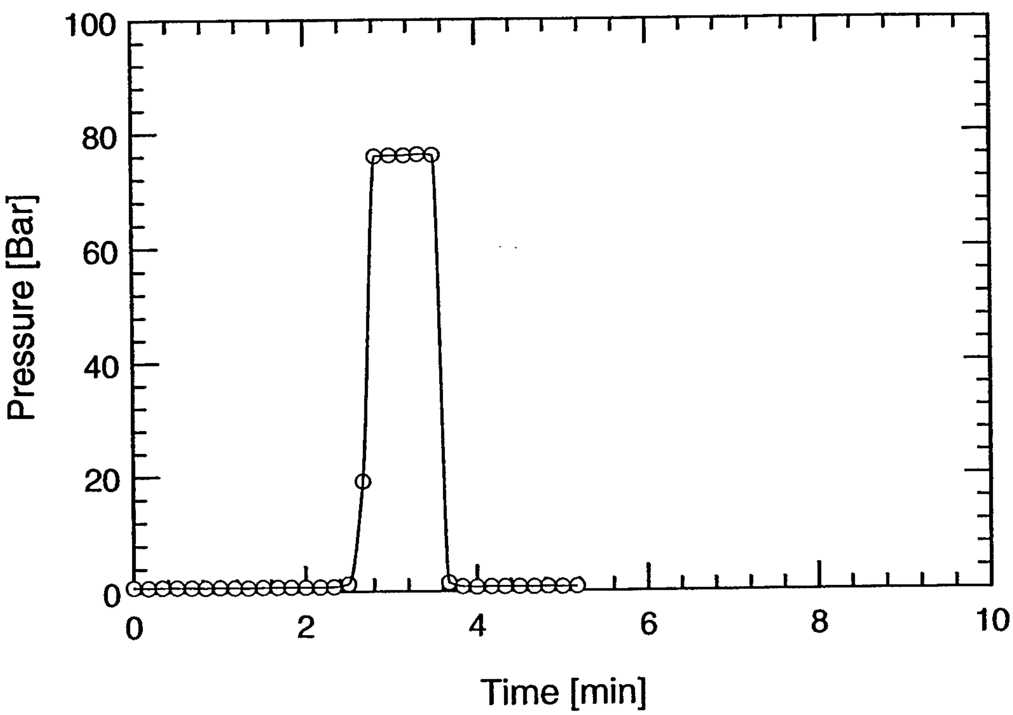


FR 22

Test #45

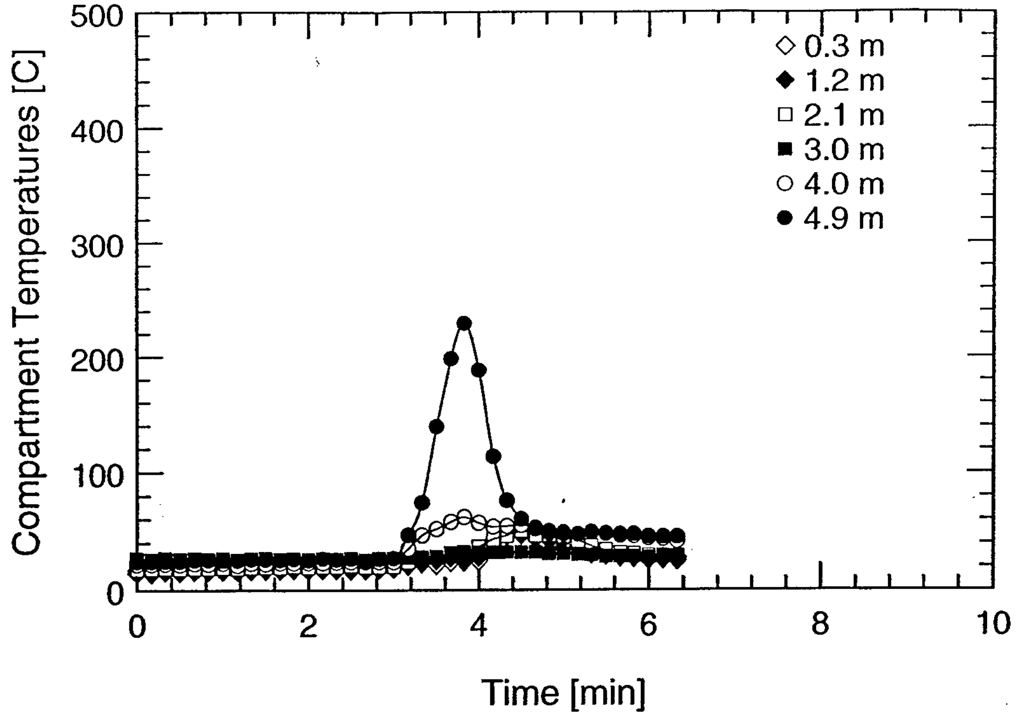


Water Mist System Flow Rate

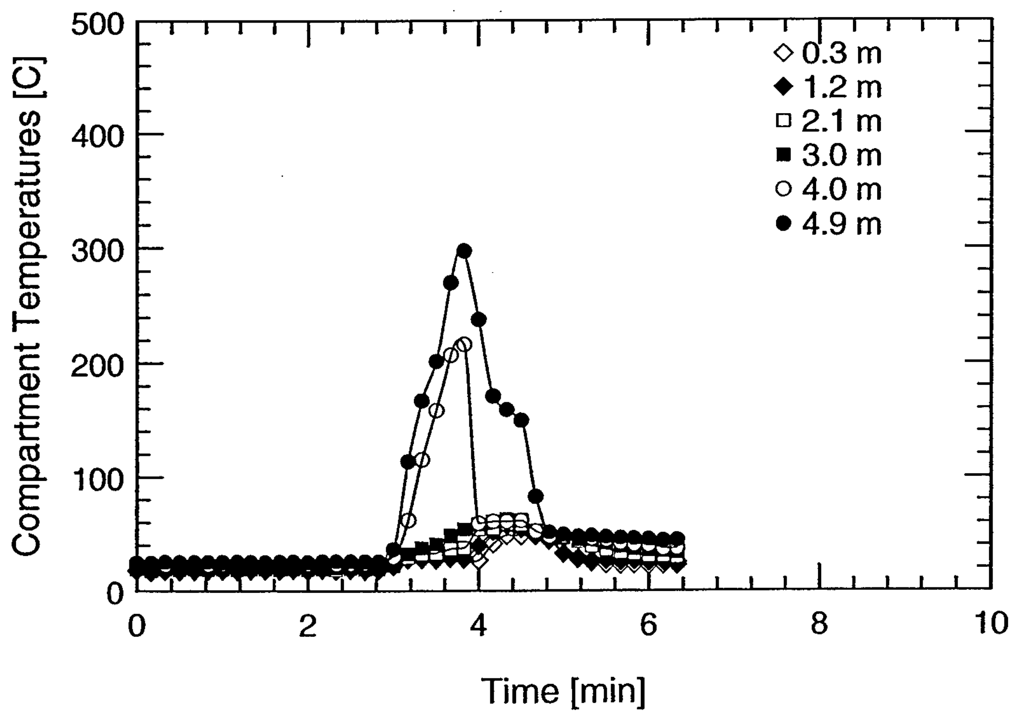


Water Mist System Pressure

Test #45

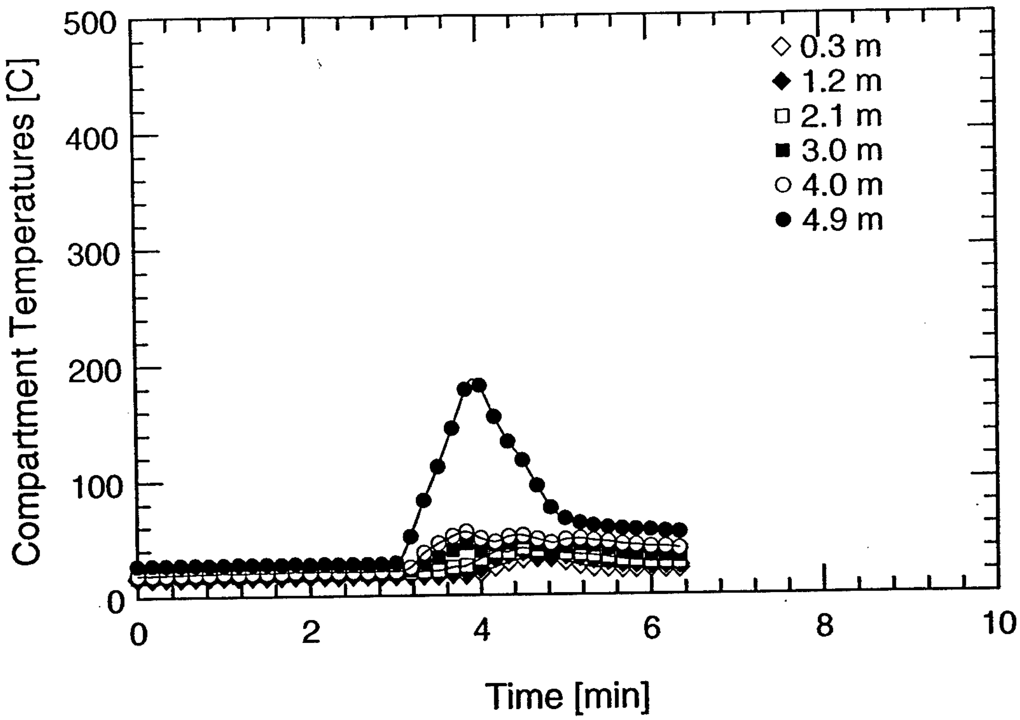


5-22-1

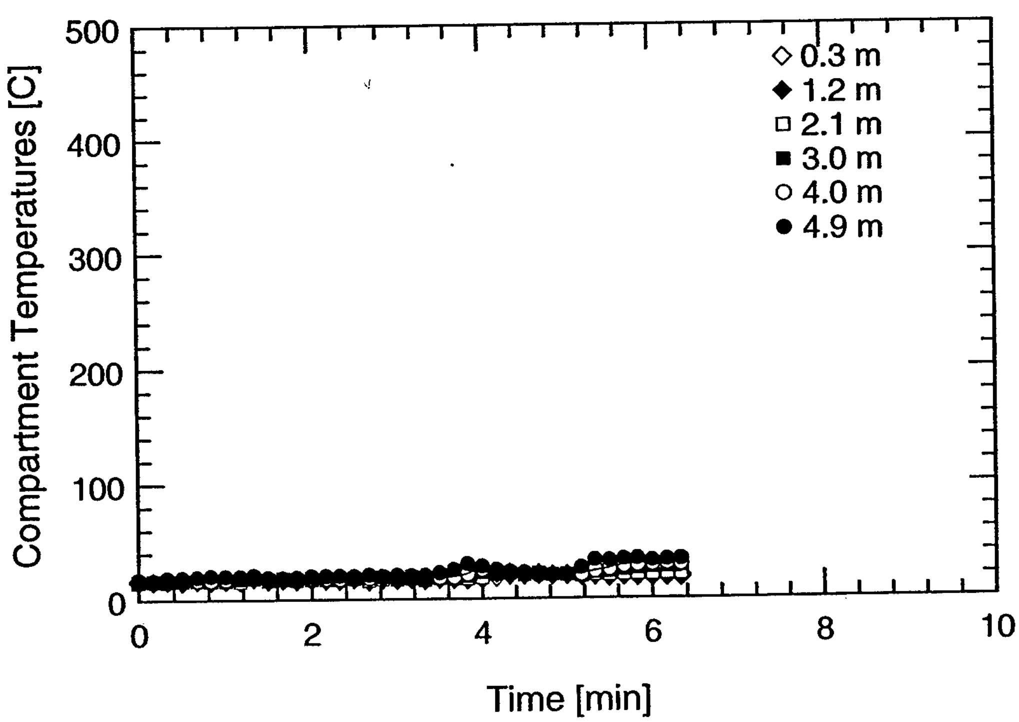


5-27-1

Test #46

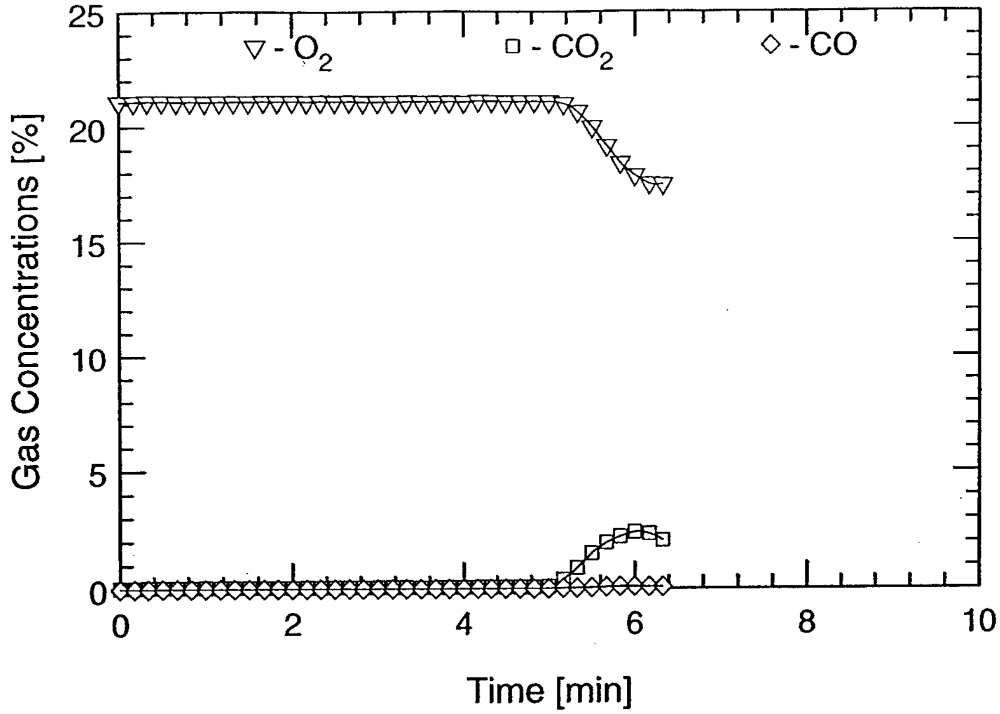


5-27-2

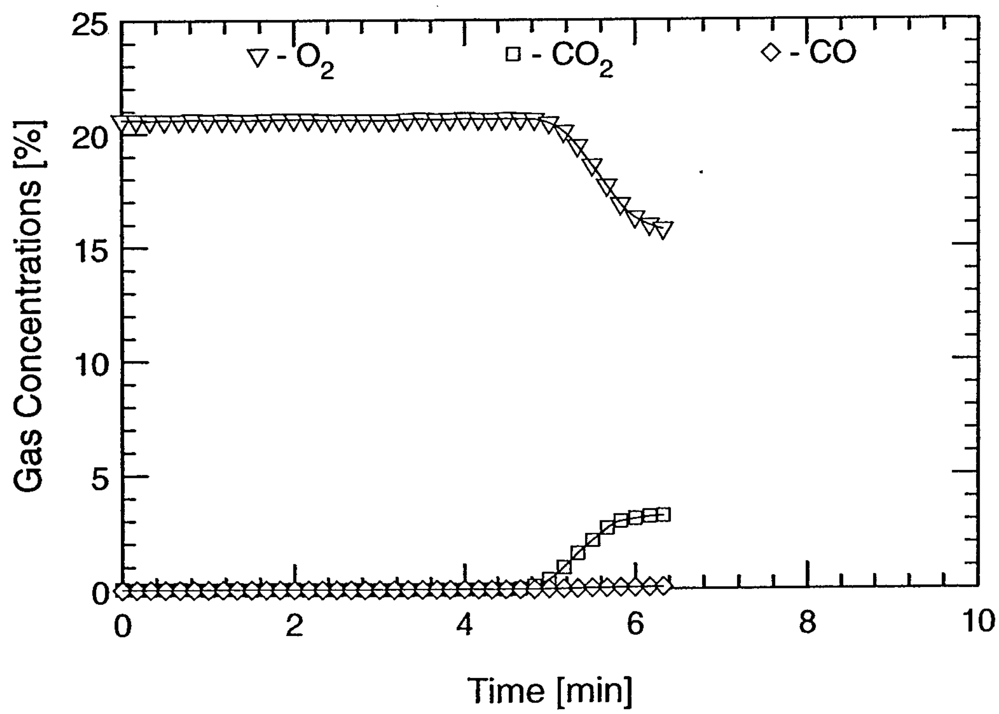


5-35-1

Test #46

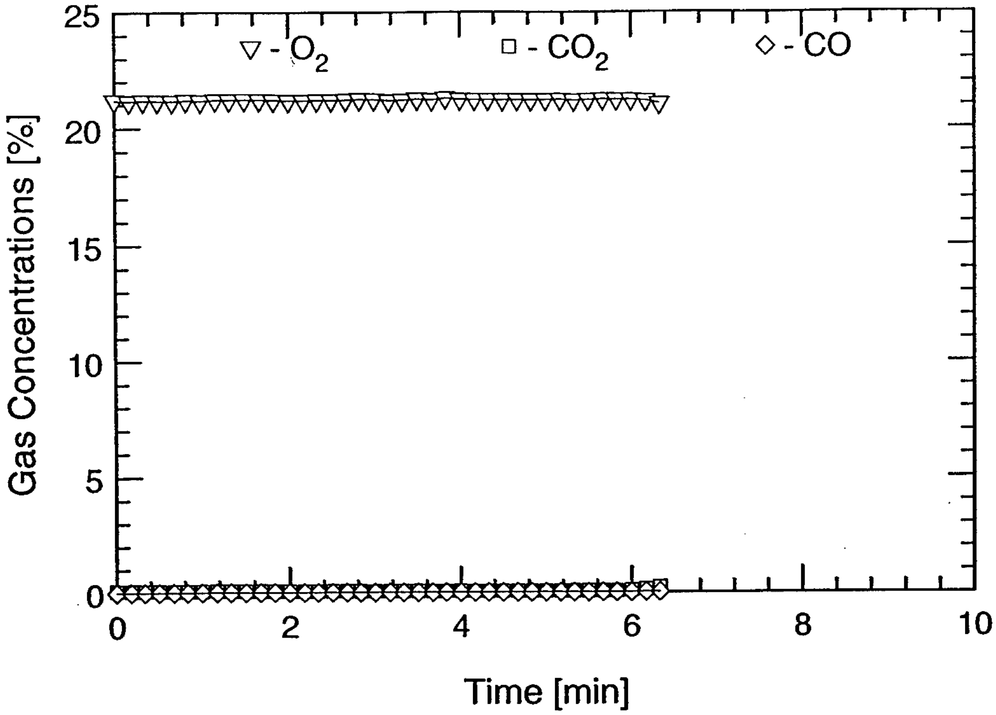


FR 22 - 0.5 m

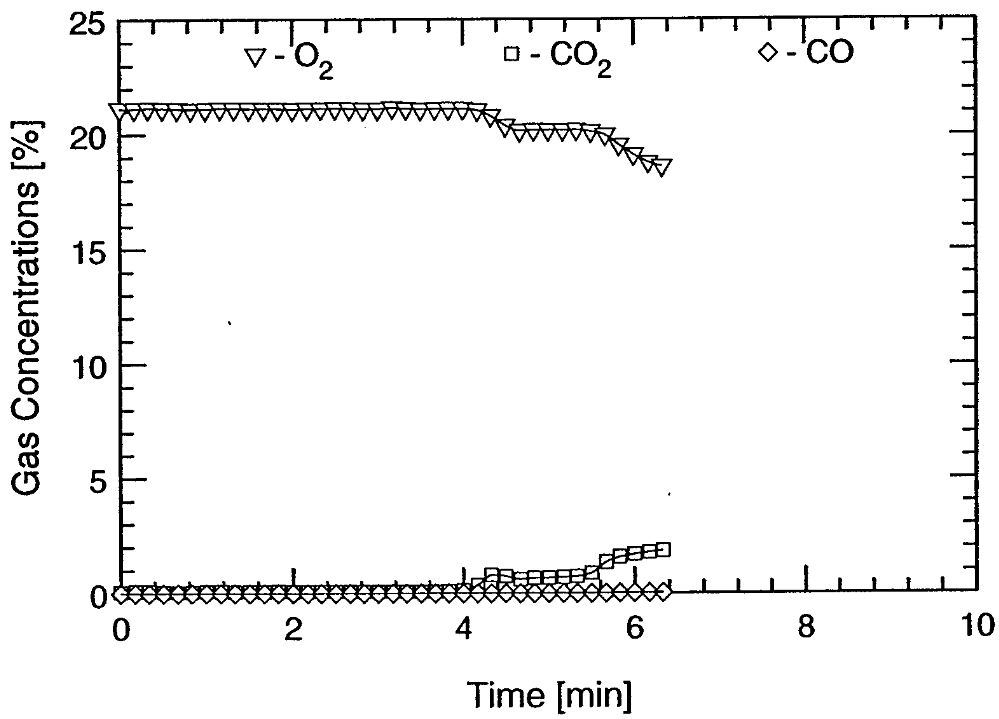


FR 22 - 4.5 m

Test #46

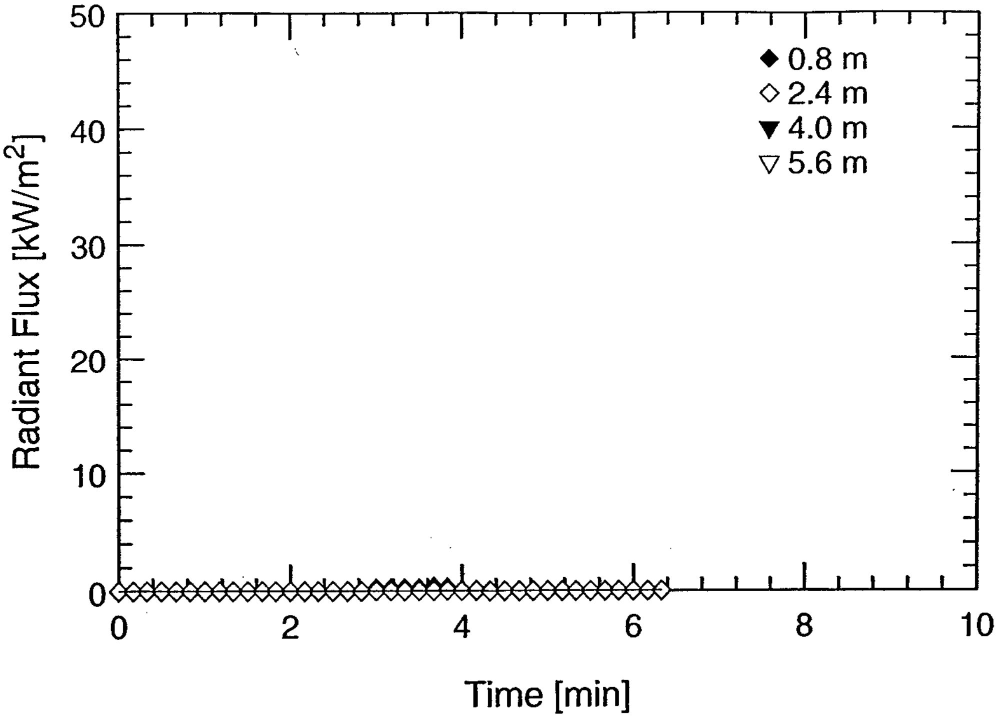


FR 36 - 0.5 m

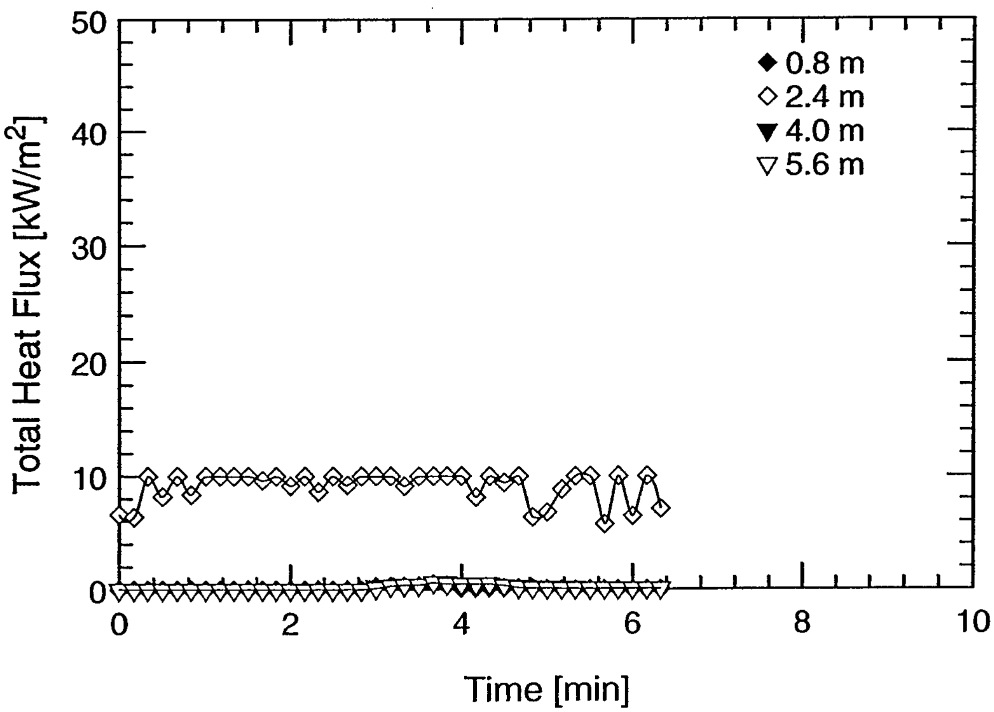


FR 36 - 4.5 m

Test #46

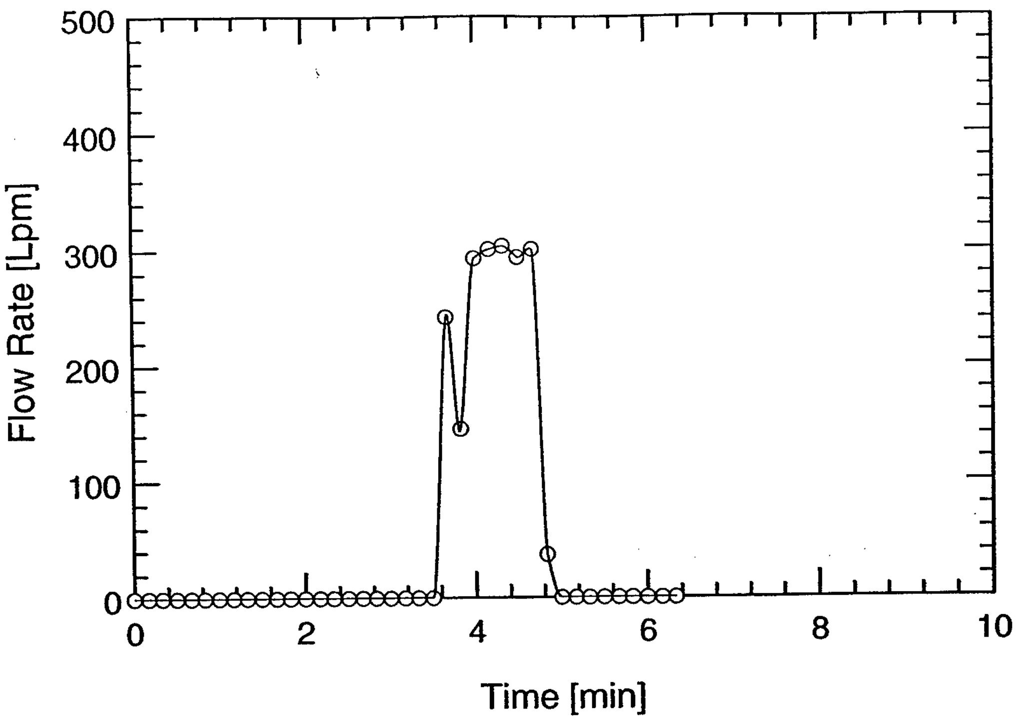


FR 22

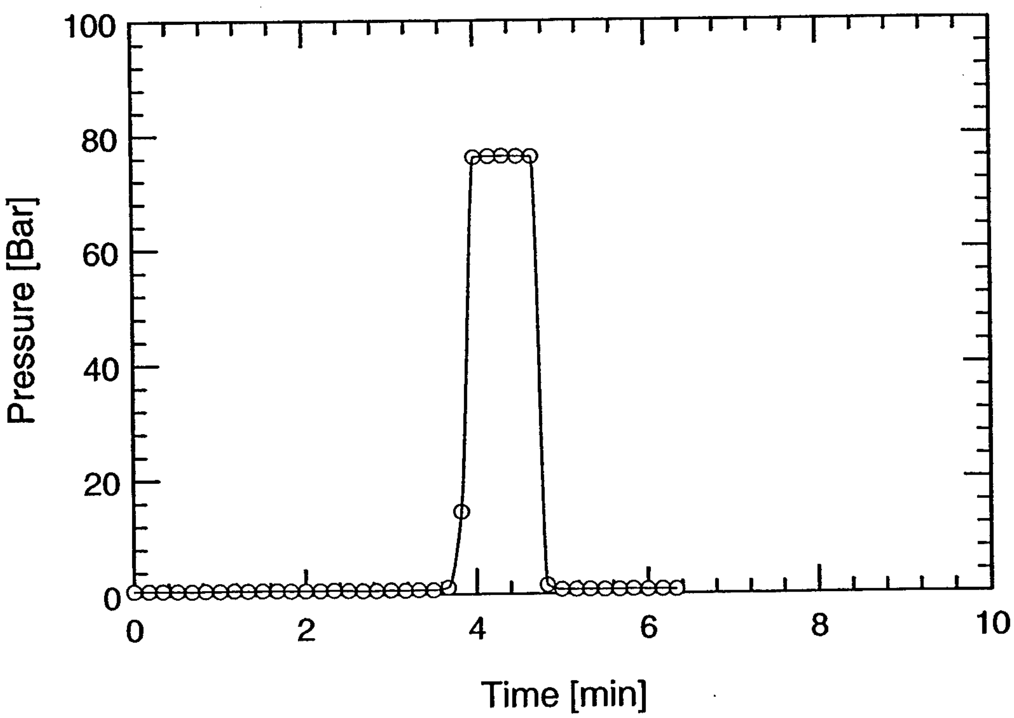


FR 22

Test #46

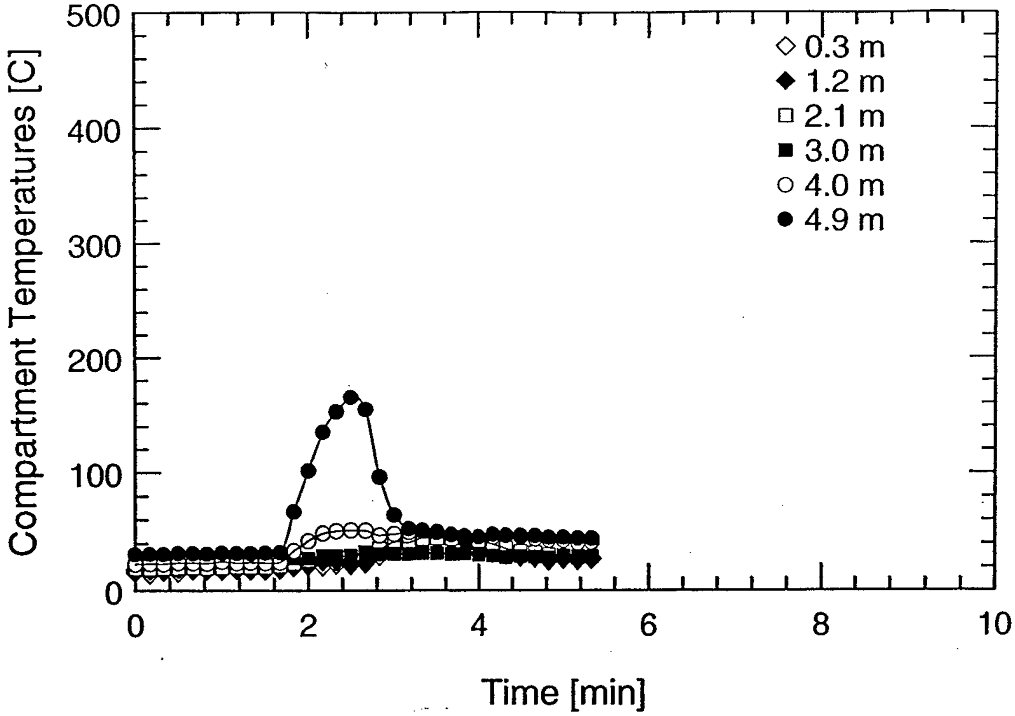


Water Mist System Flow Rate

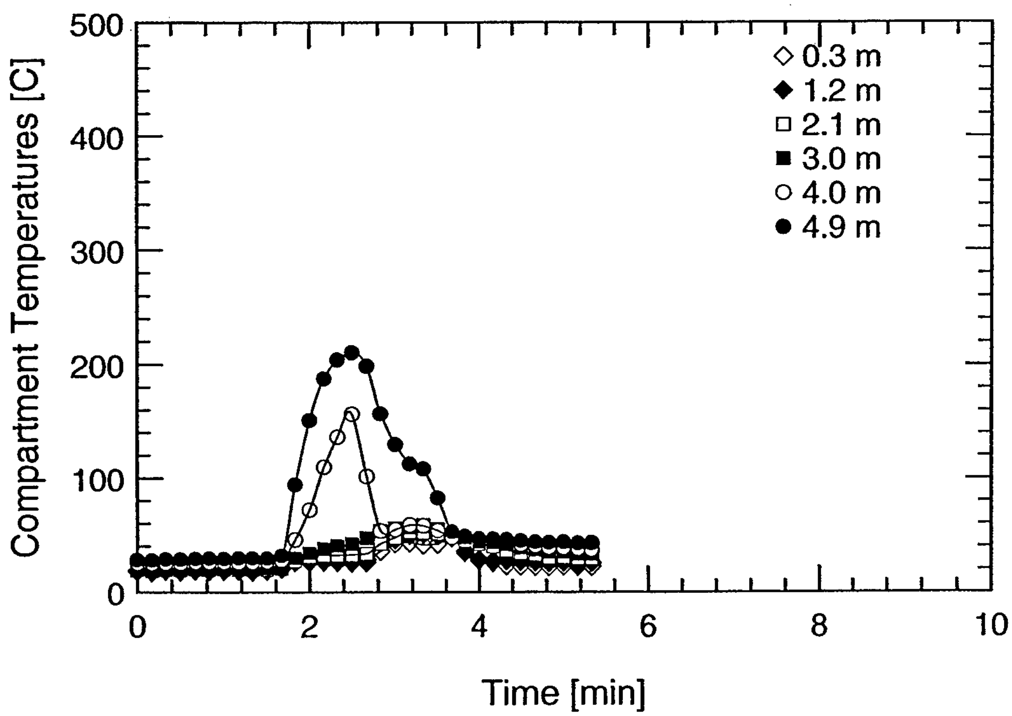


Water Mist System Pressure

Test #46

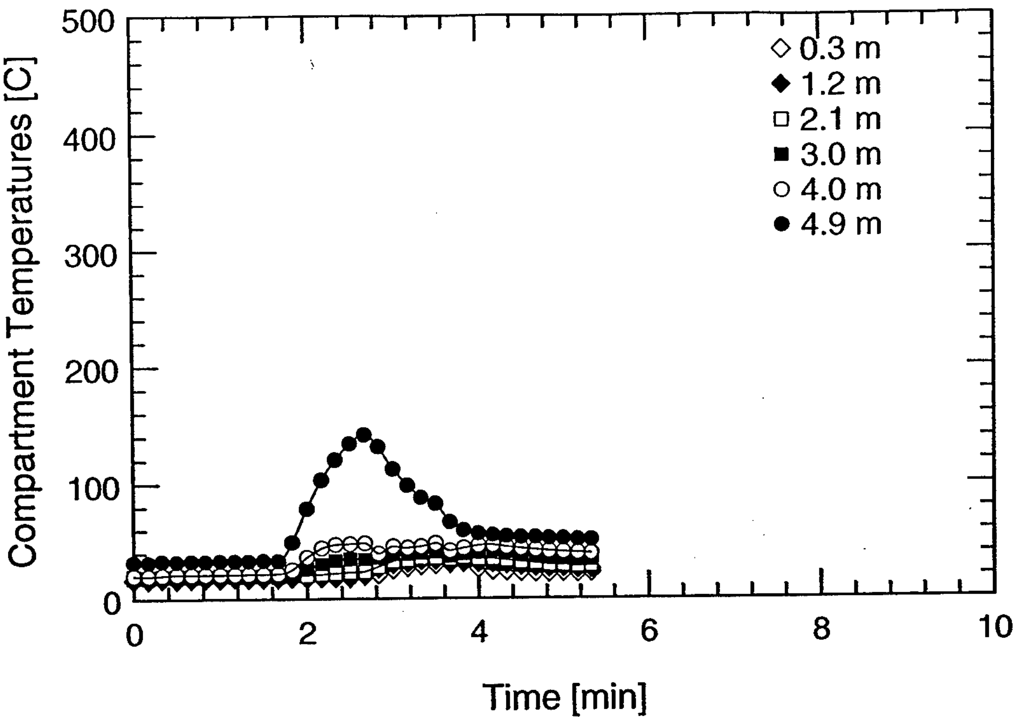


5-22-1

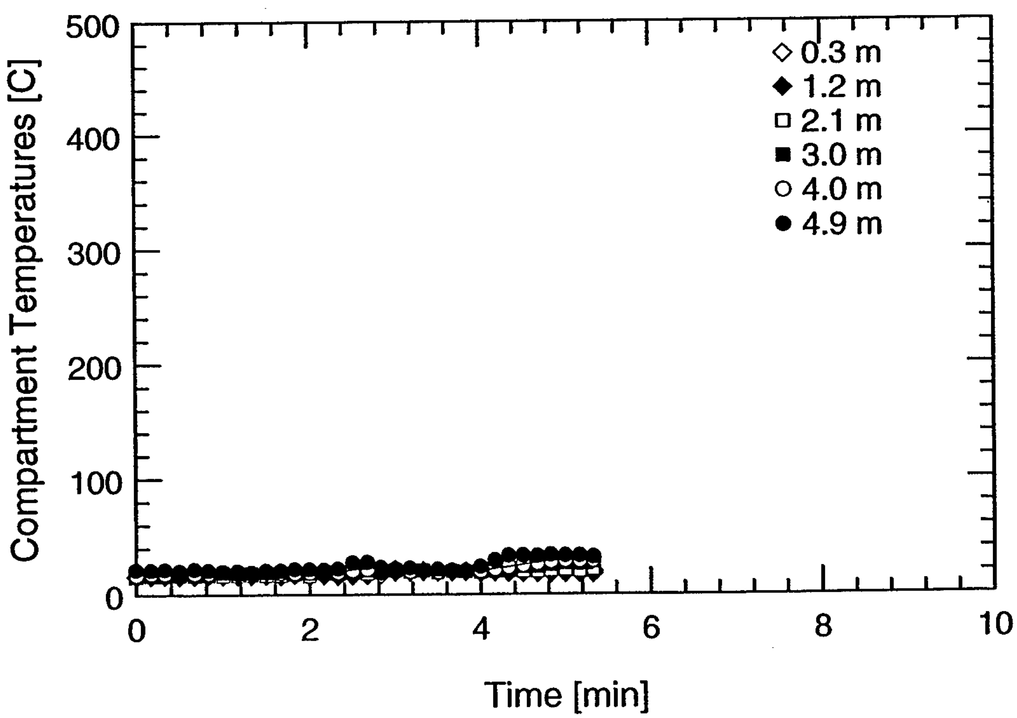


5-27-1

Test #47

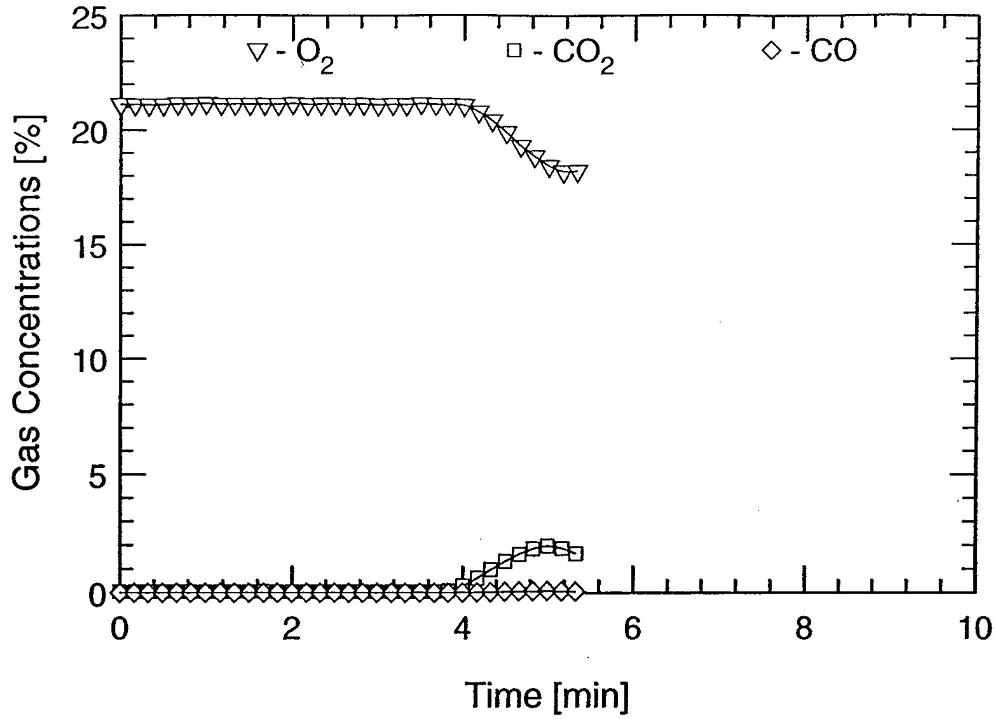


5-27-2

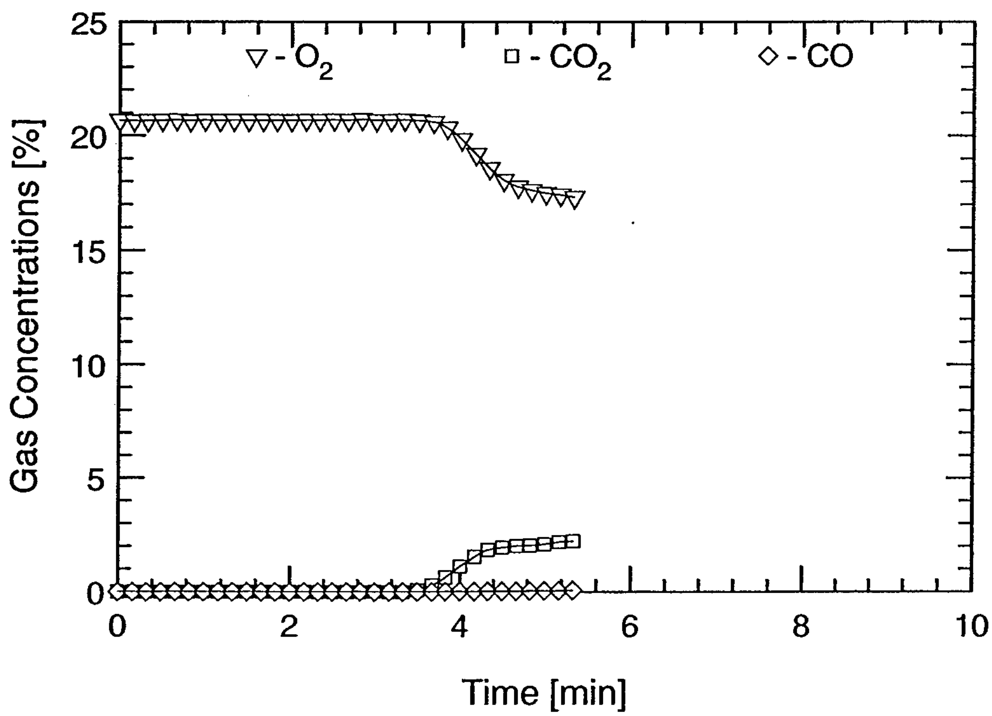


5-35-1

Test #47

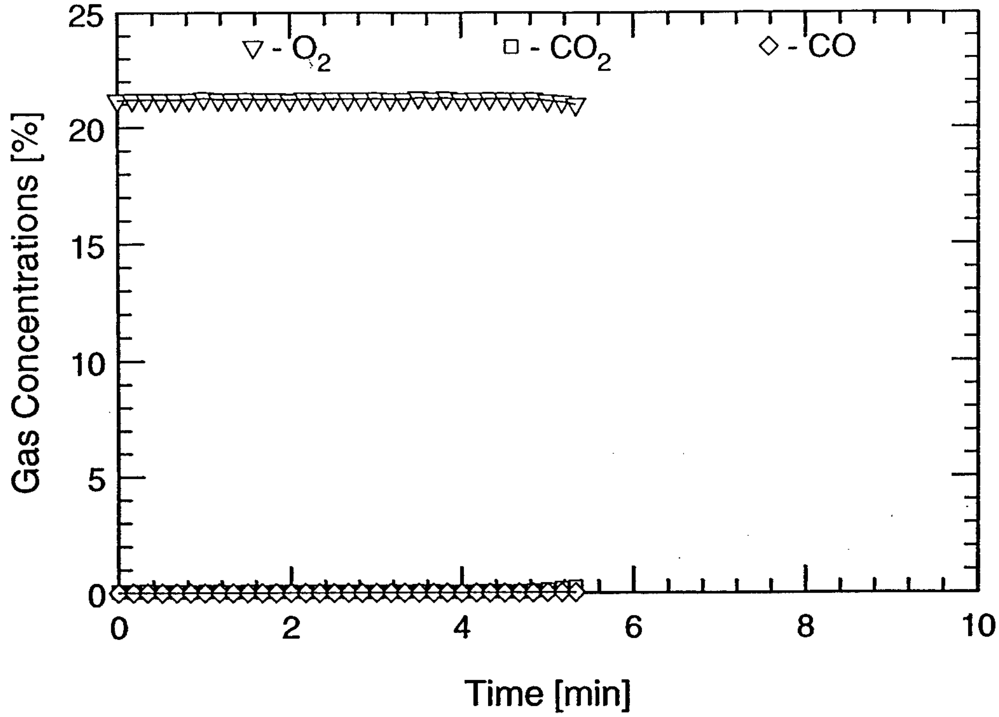


FR 22 - 0.5 m

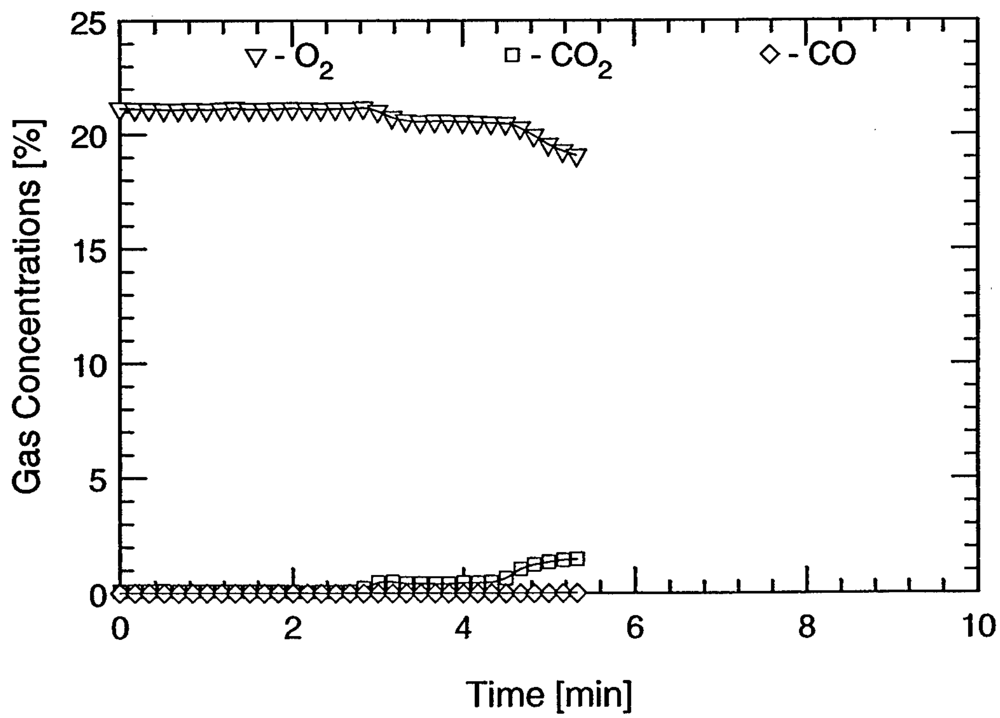


FR 22 - 4.5 m

Test #47

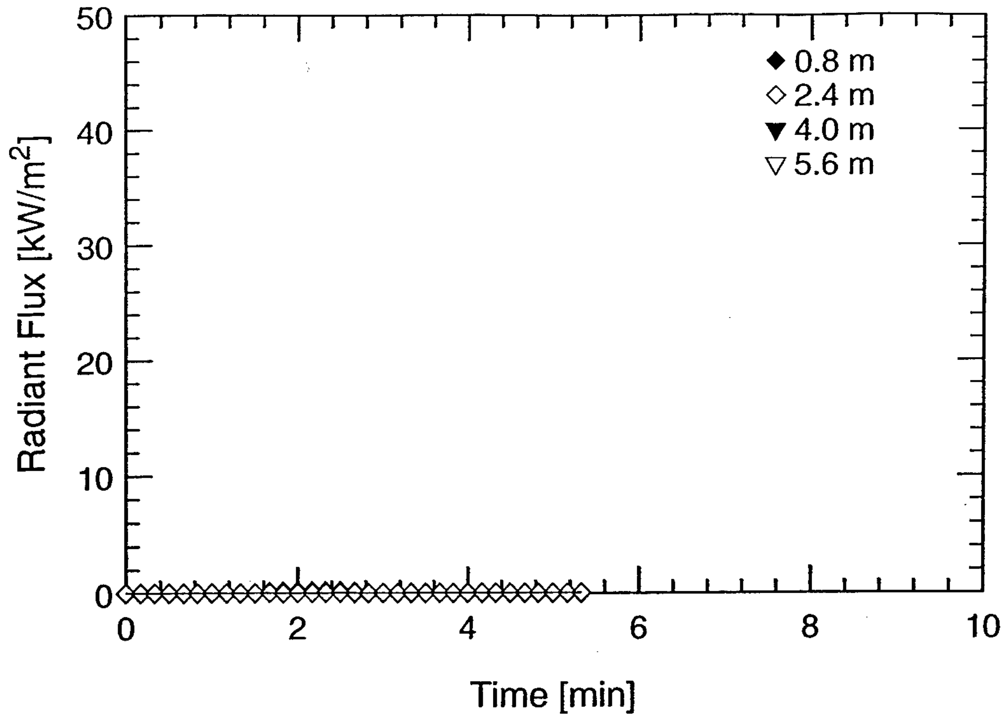


FR 36 - 0.5 m

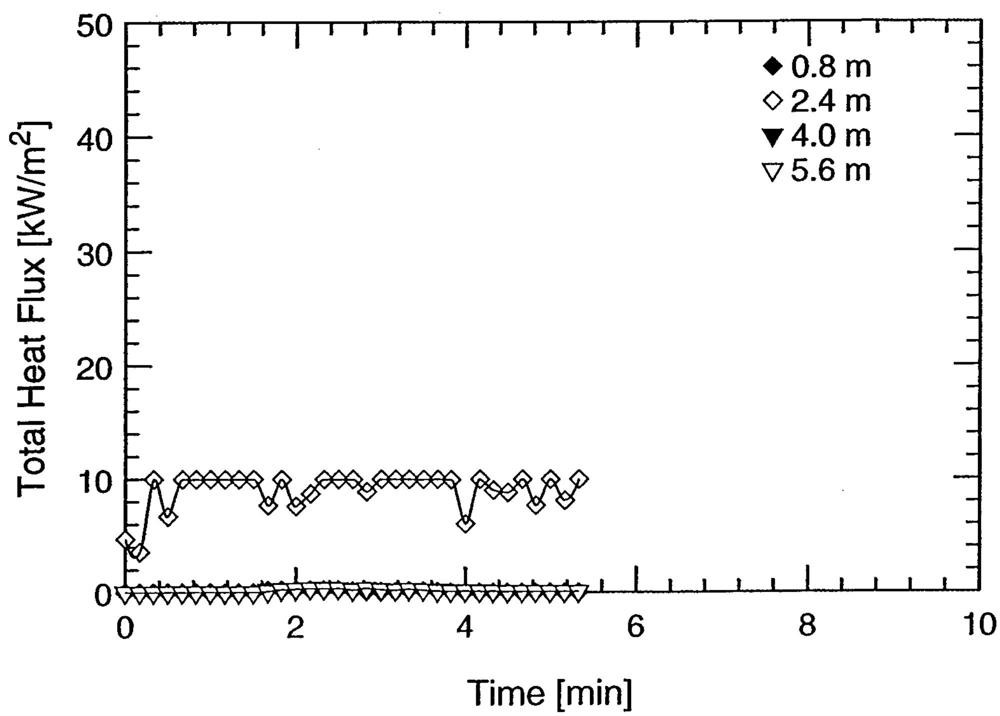


FR 36 - 4.5 m

Test #47

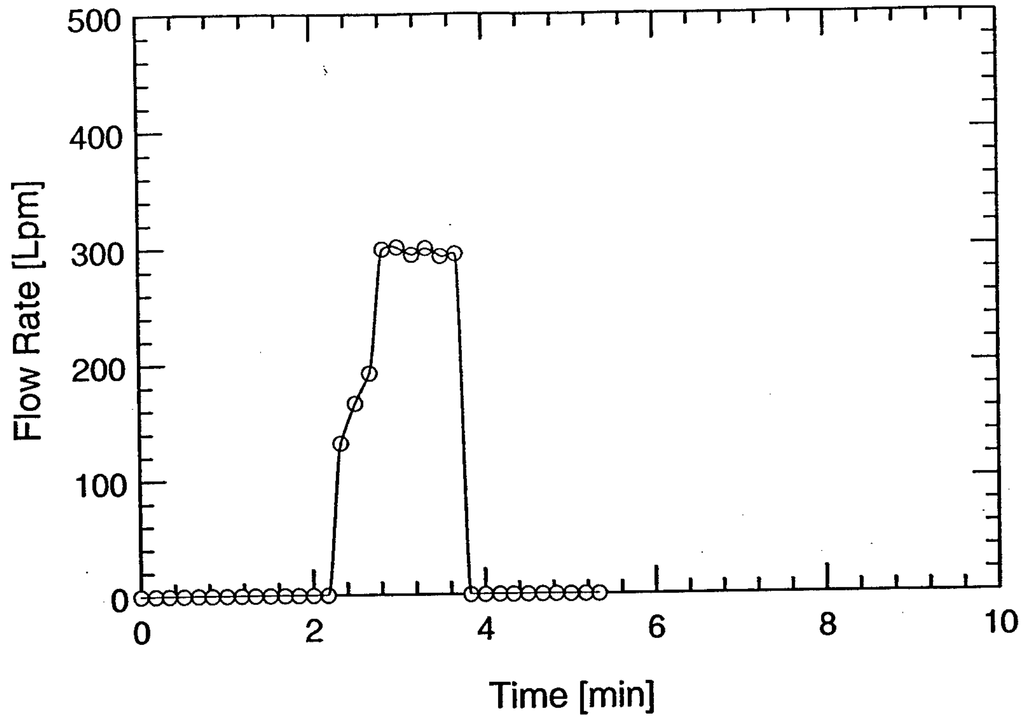


FR 22

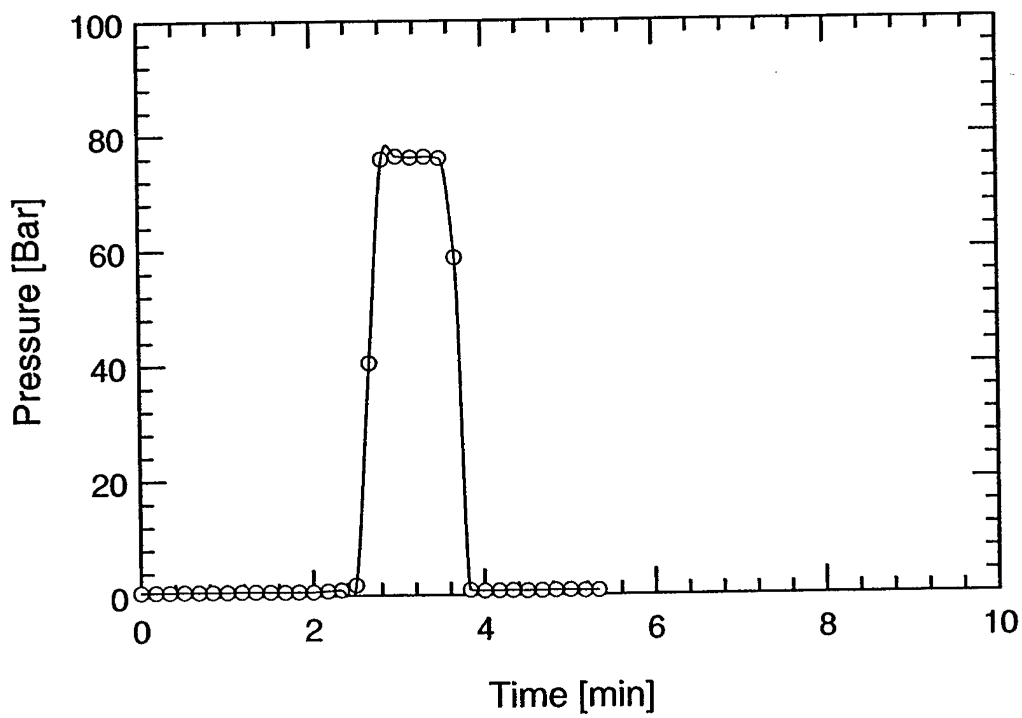


FR 22

Test #47

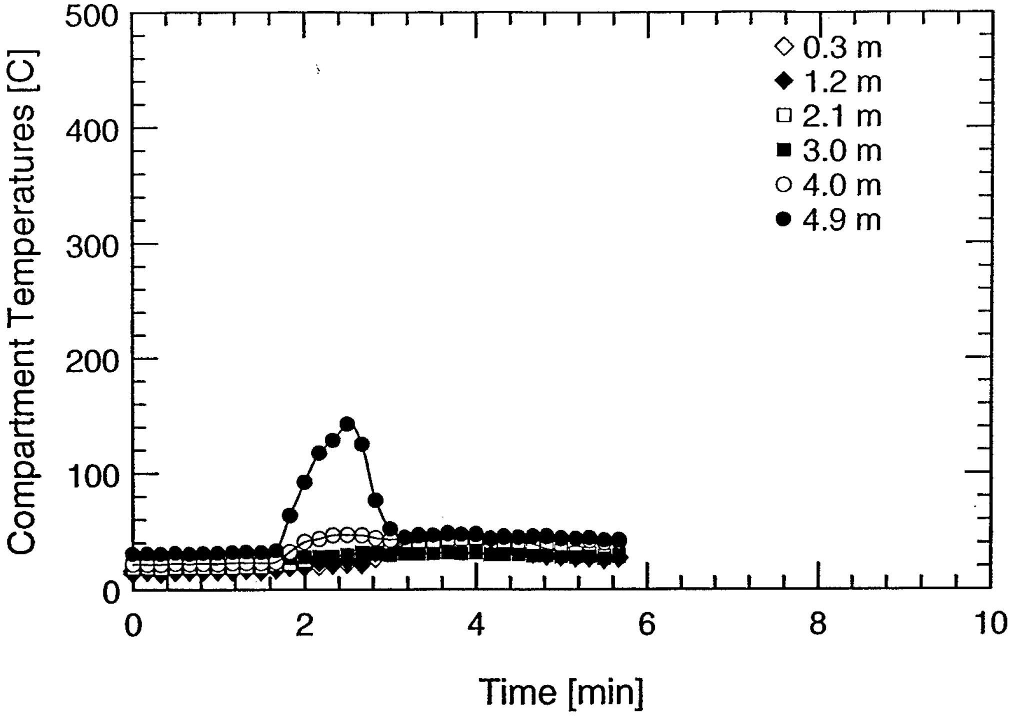


Water Mist System Flow Rate

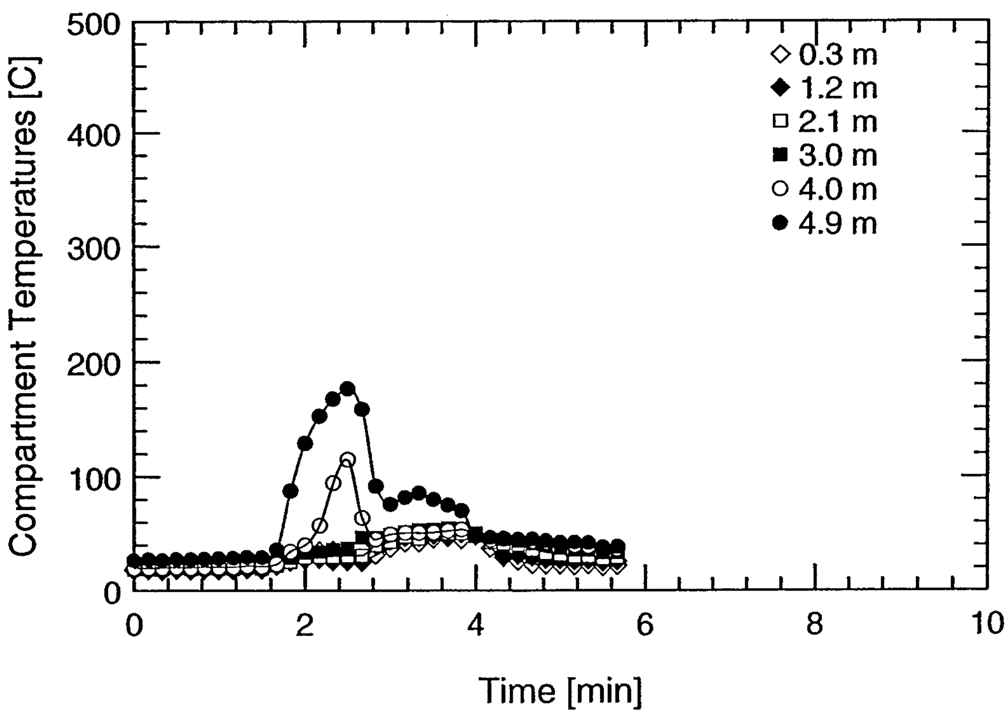


Water Mist System Pressure

Test #47

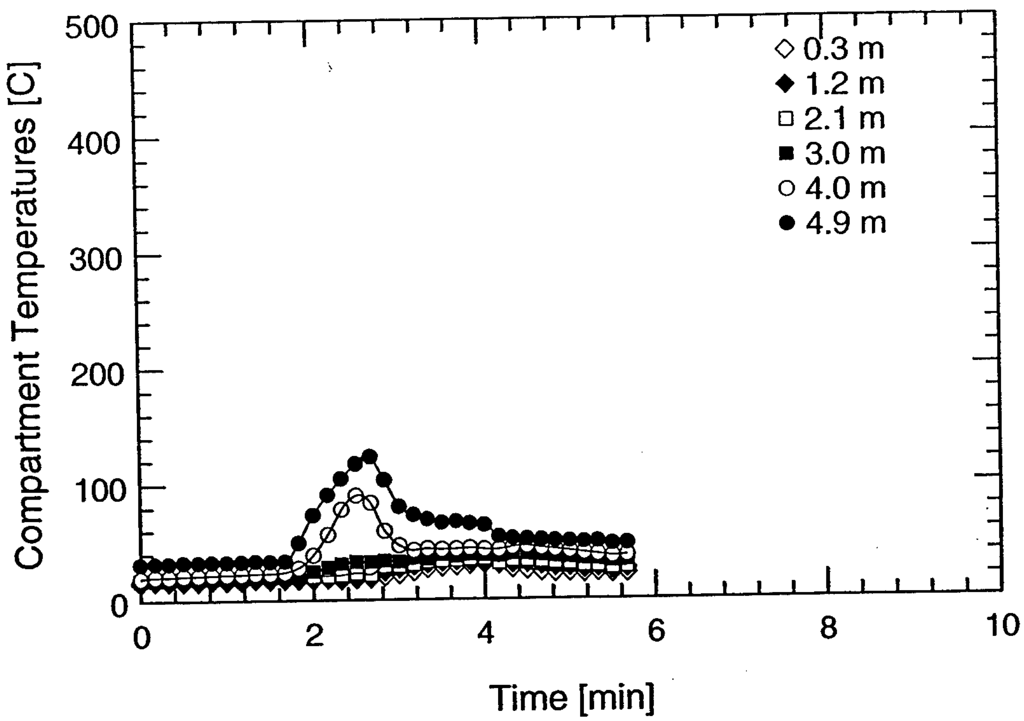


5-22-1

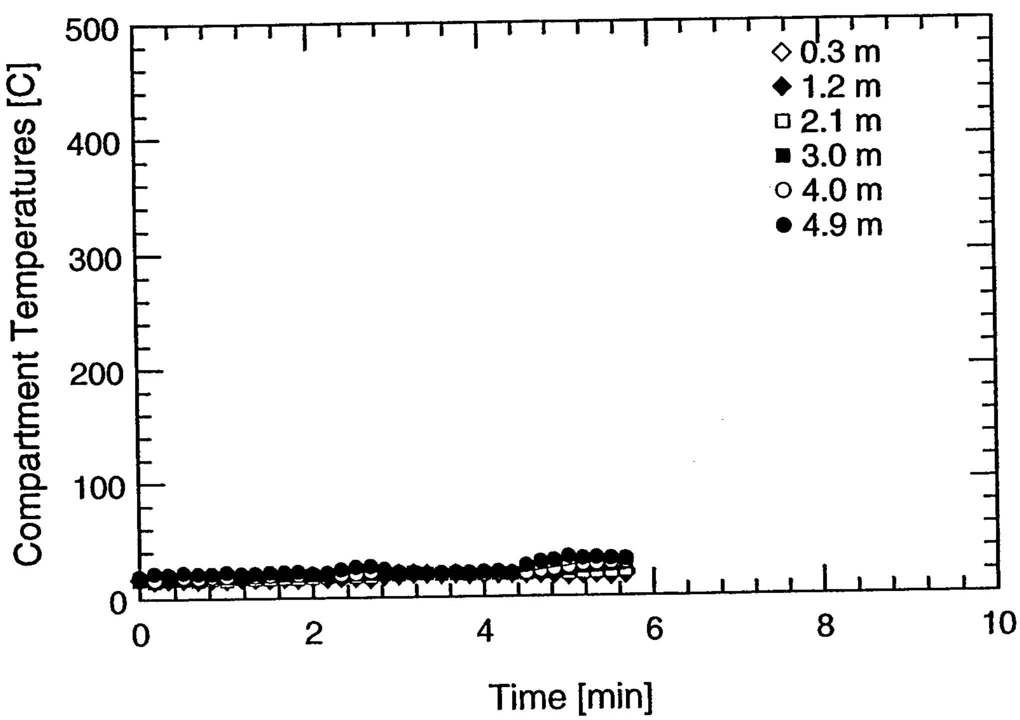


5-27-1

Test #48

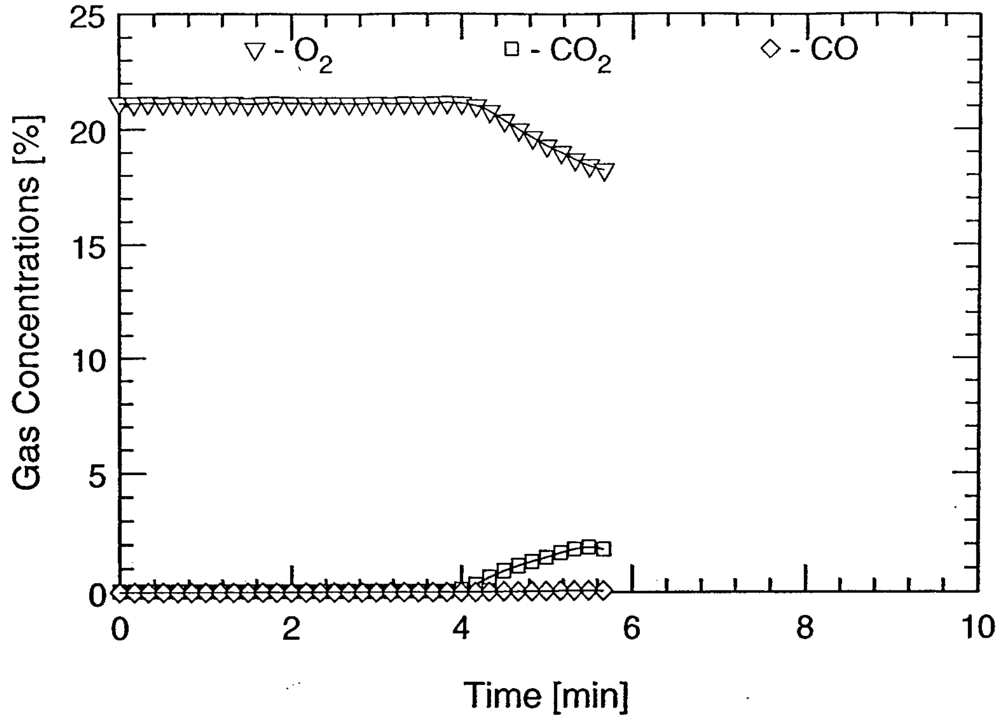


5-27-2

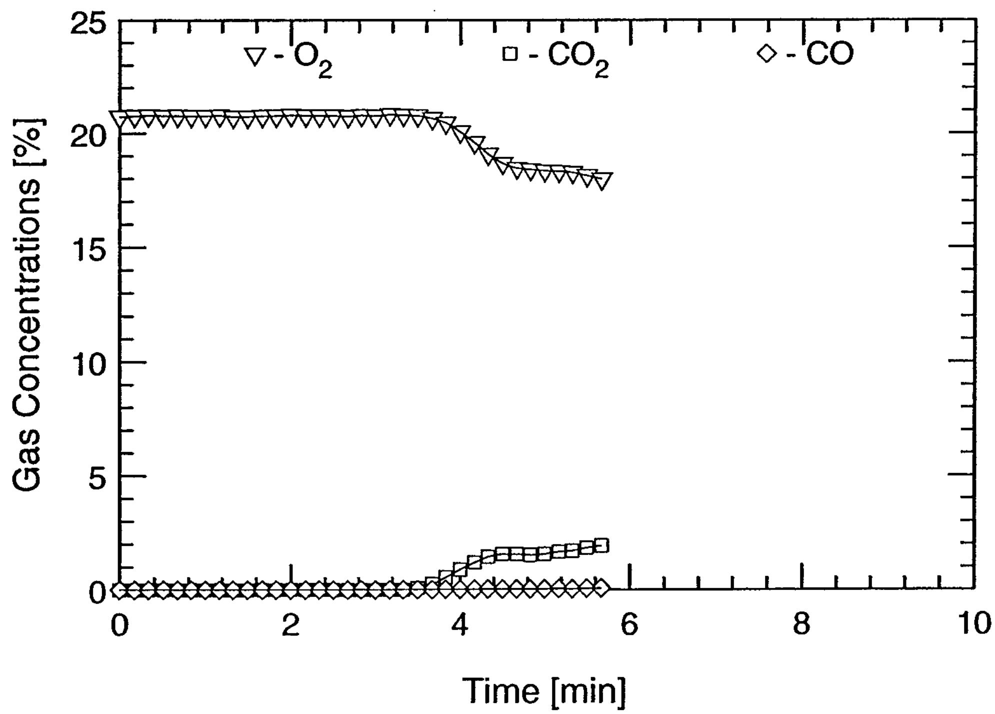


5-35-1

Test #48

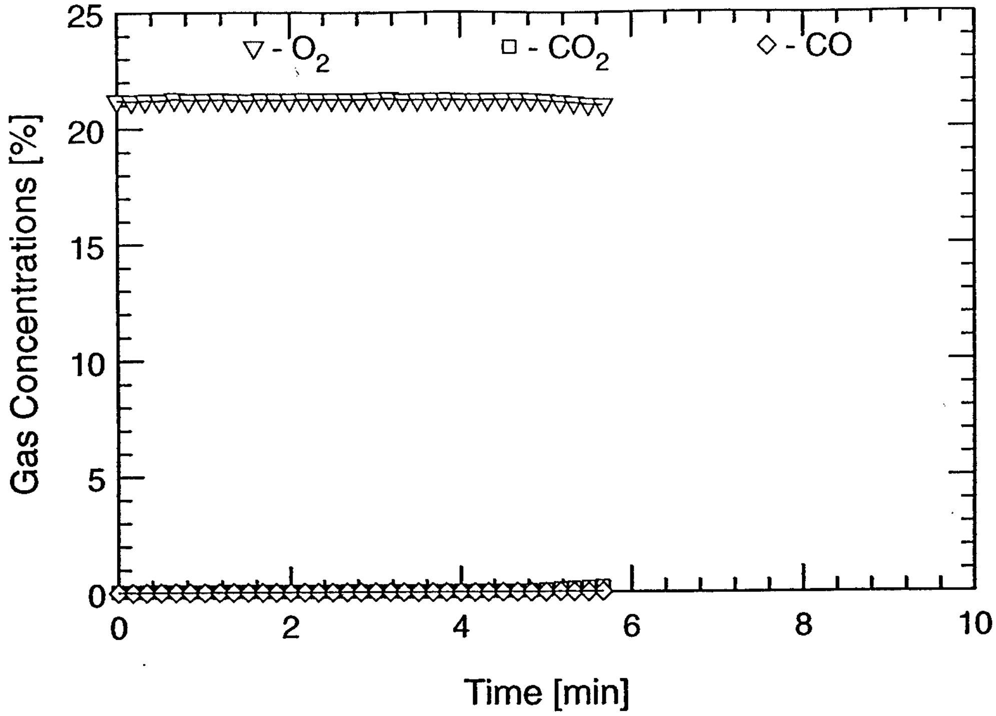


FR 22 - 0.5 m

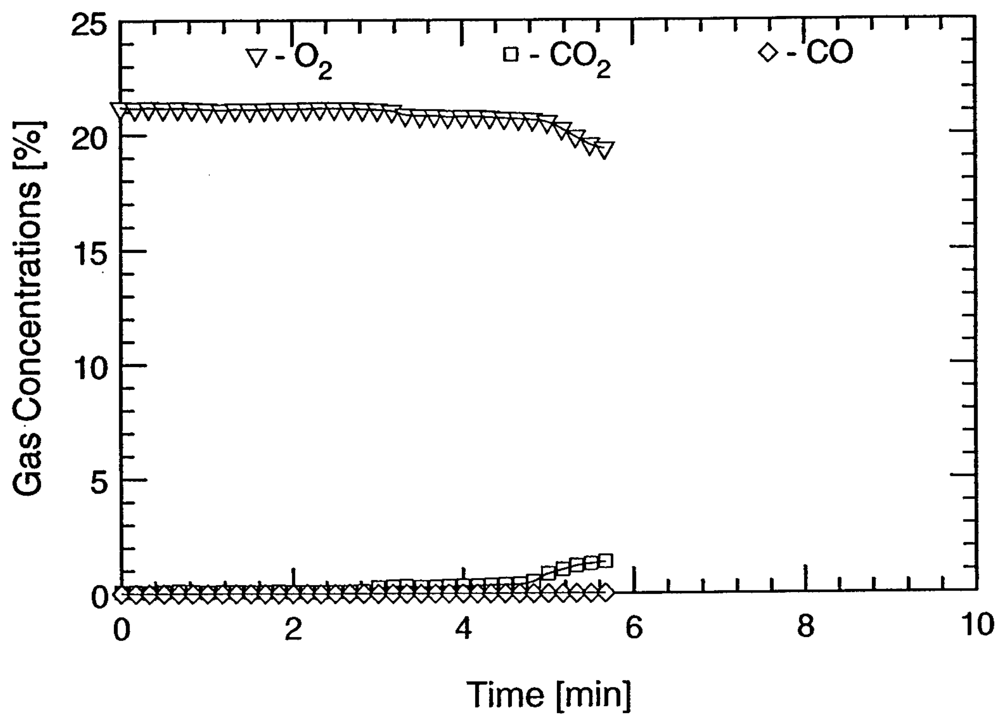


FR 22 - 4.5 m

Test #48

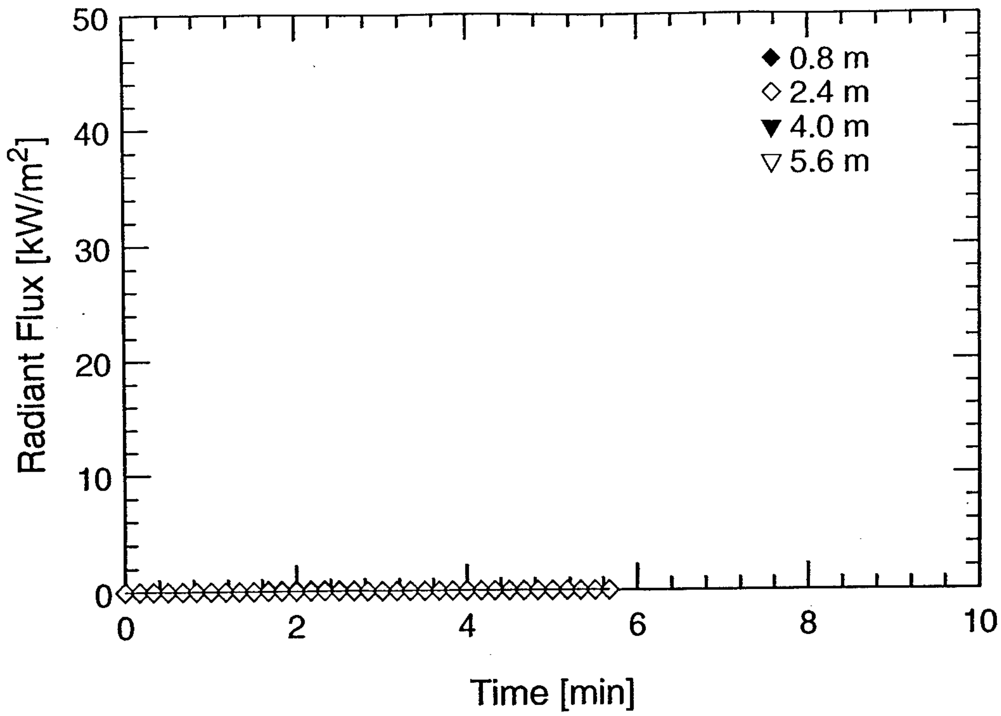


FR 36 - 0.5 m

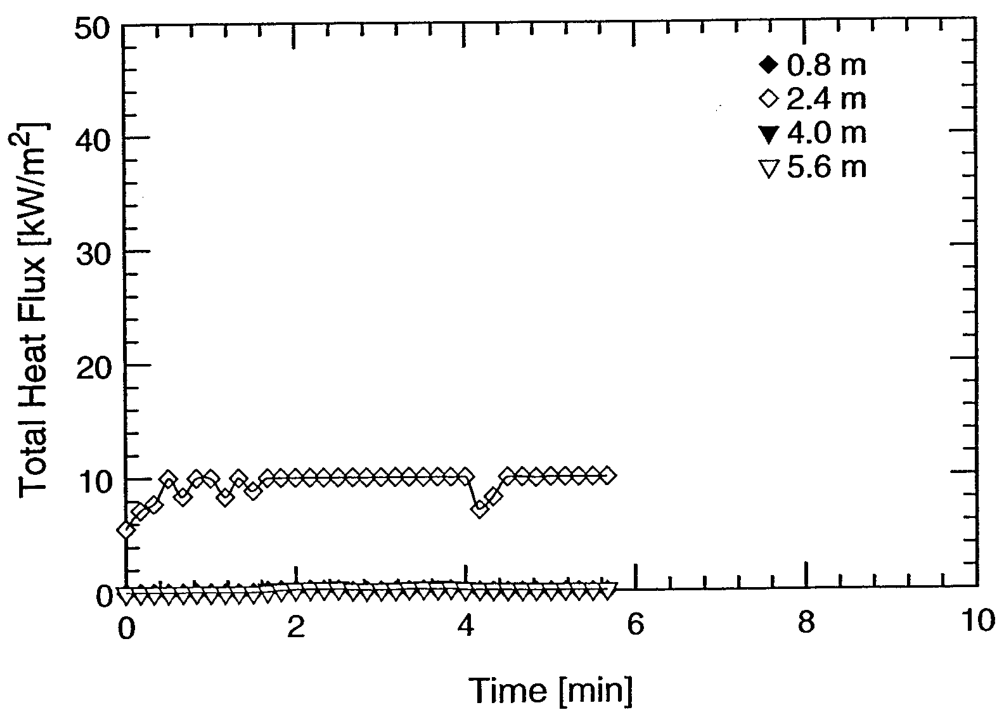


FR 36 - 4.5 m

Test #48

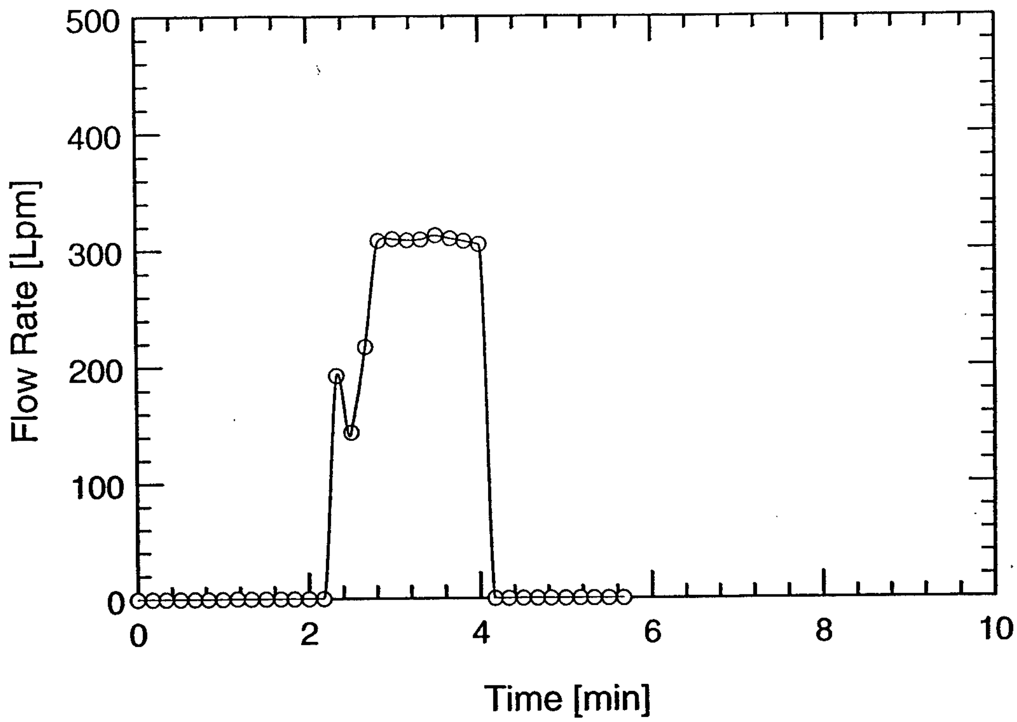


FR 22

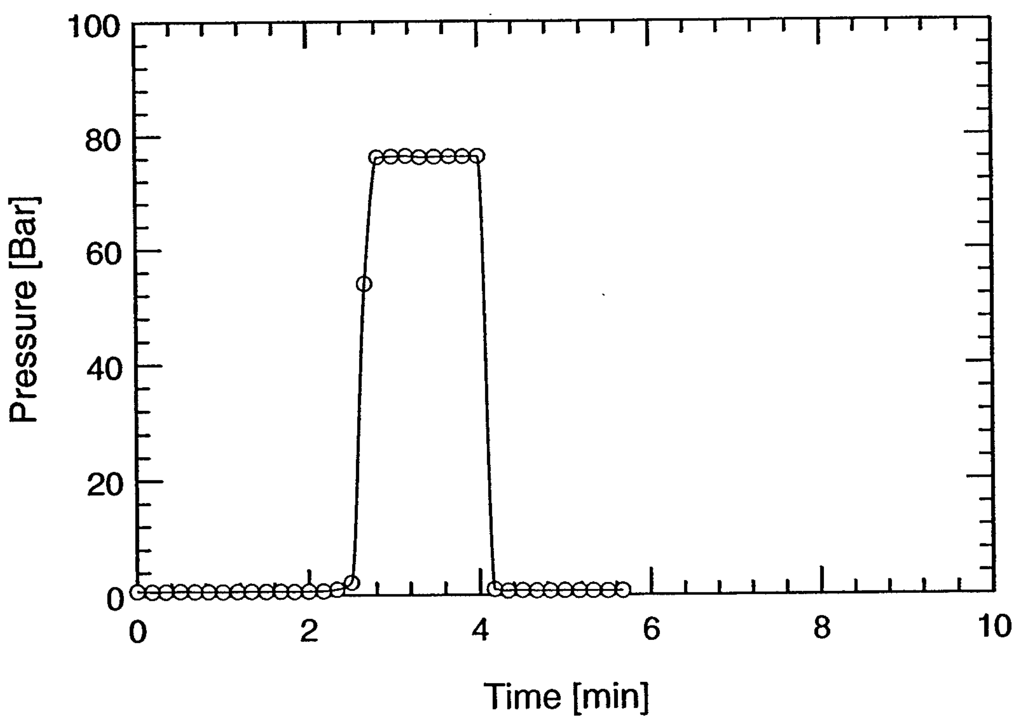


FR 22

Test #48

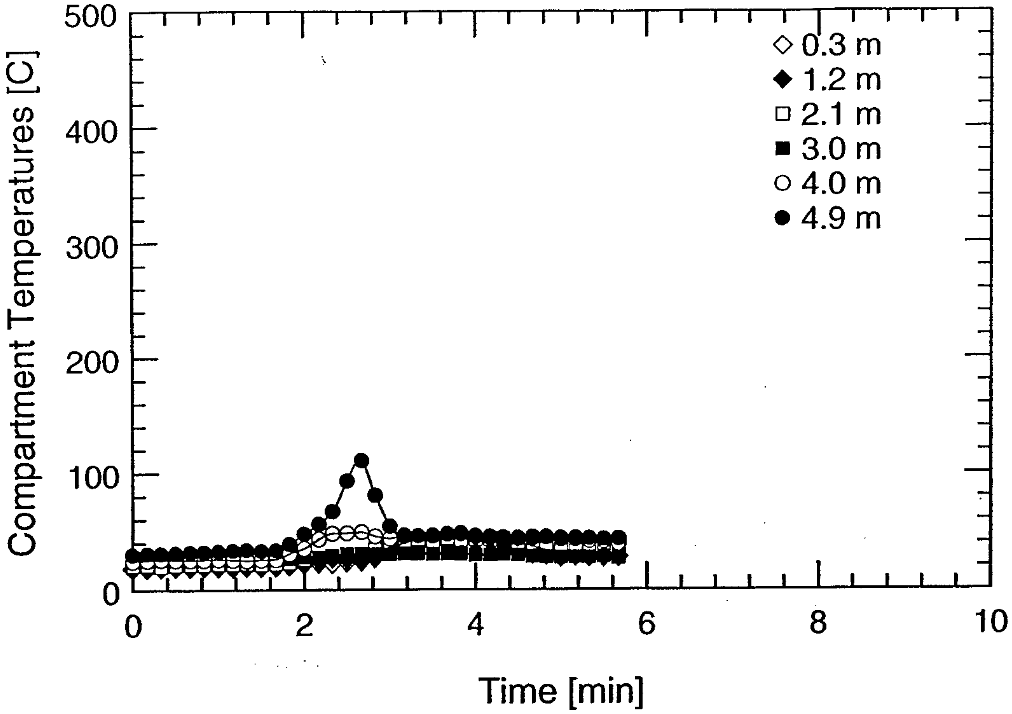


Water Mist System Flow Rate

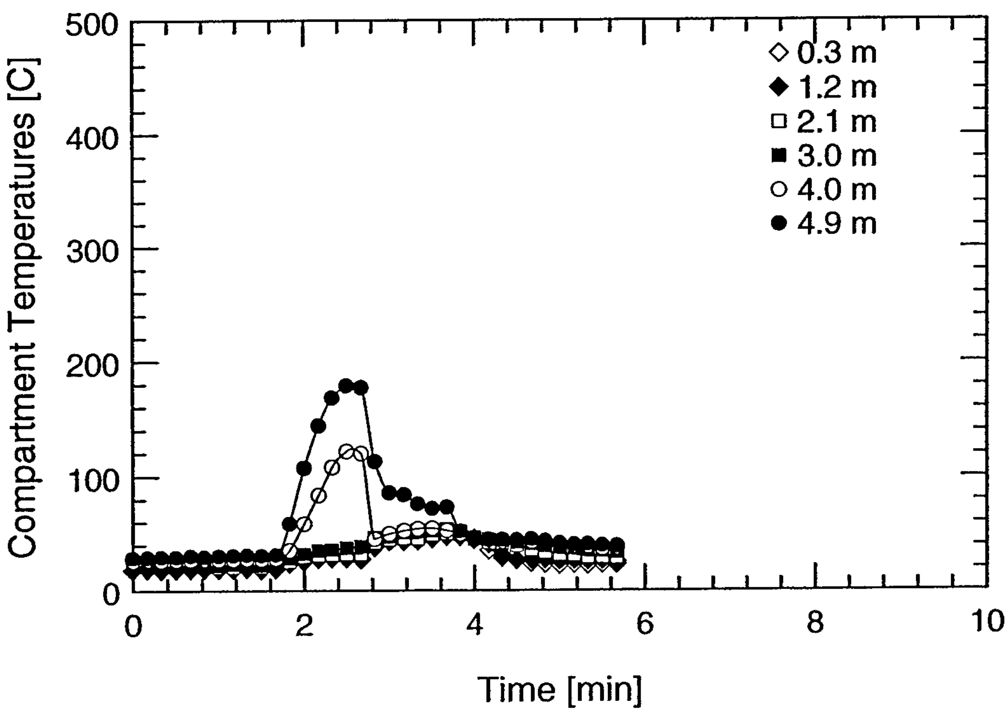


Water Mist System Pressure

Test #48

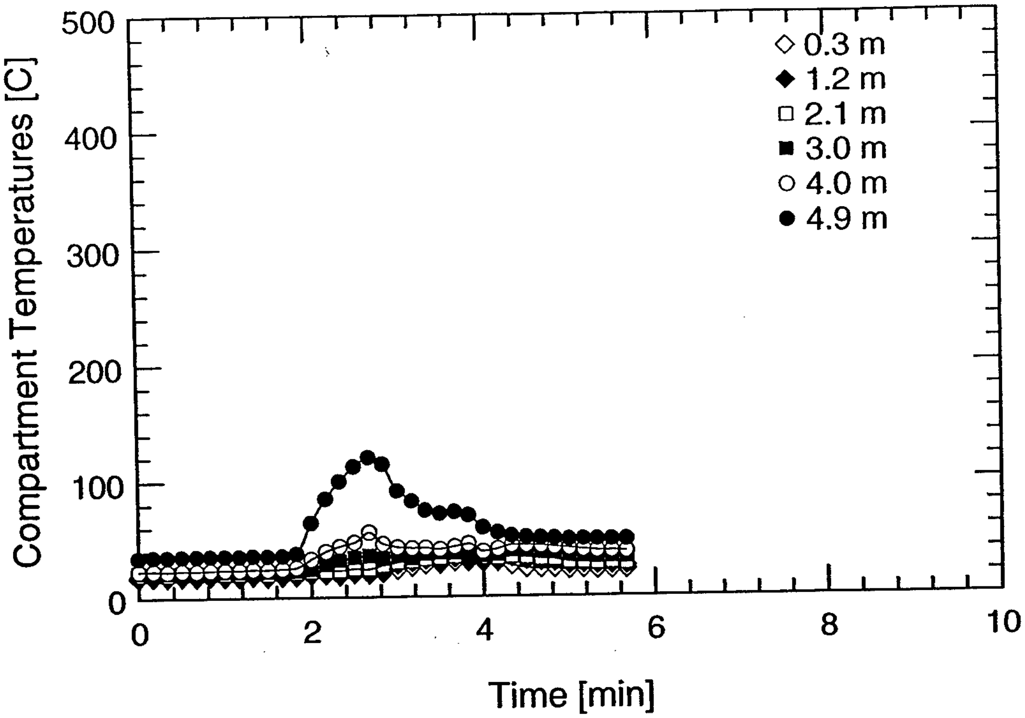


5-22-1

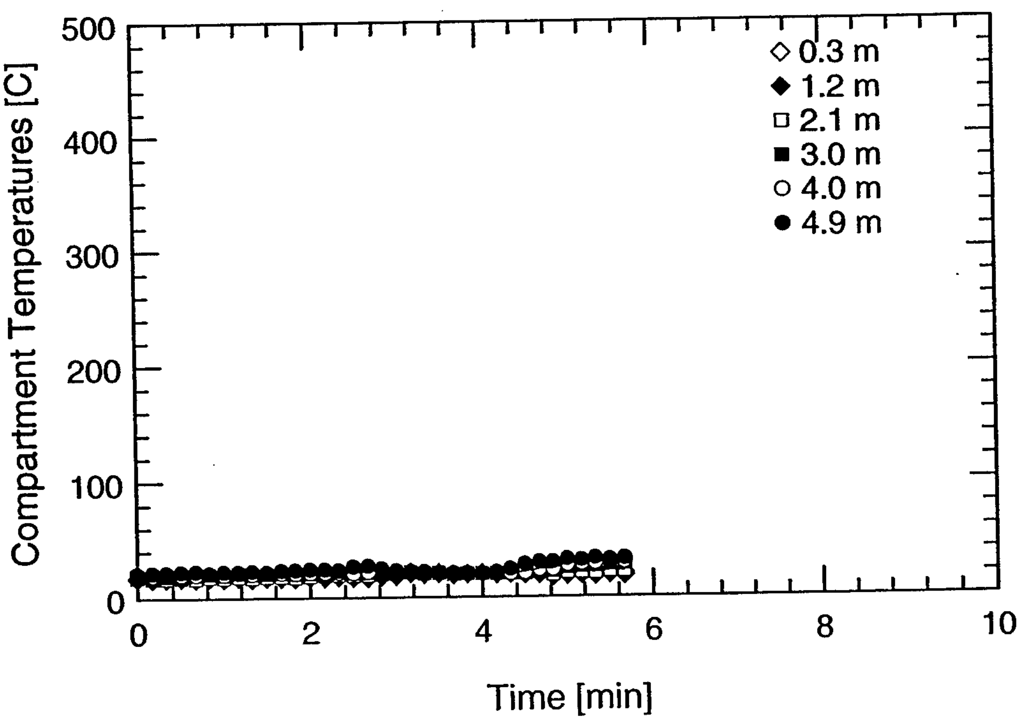


5-27-1

Test #49

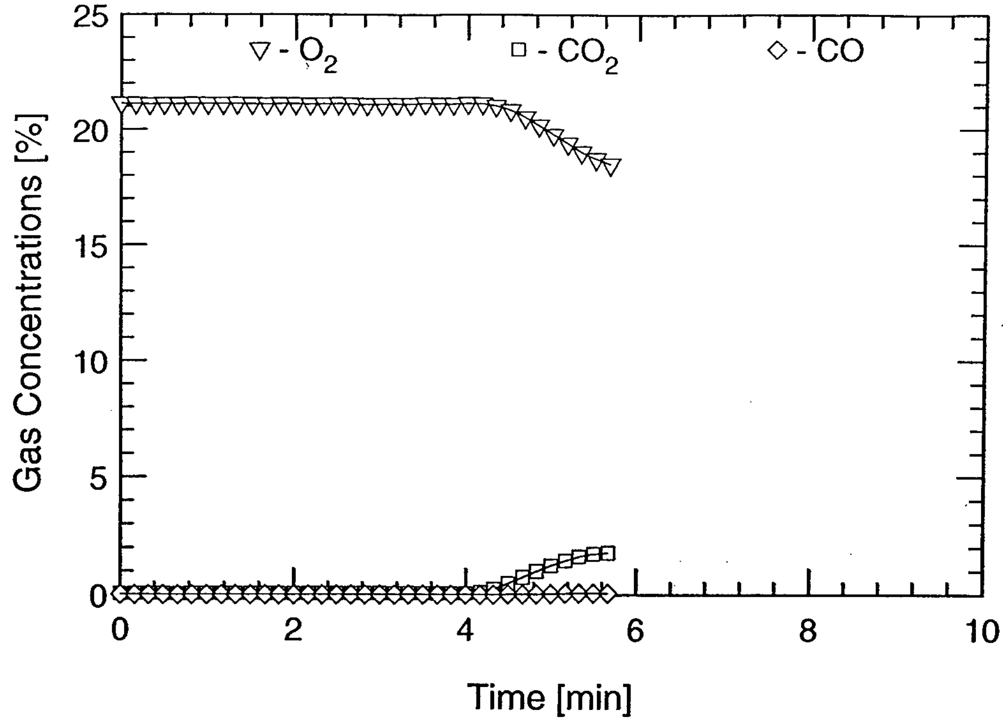


5-27-2

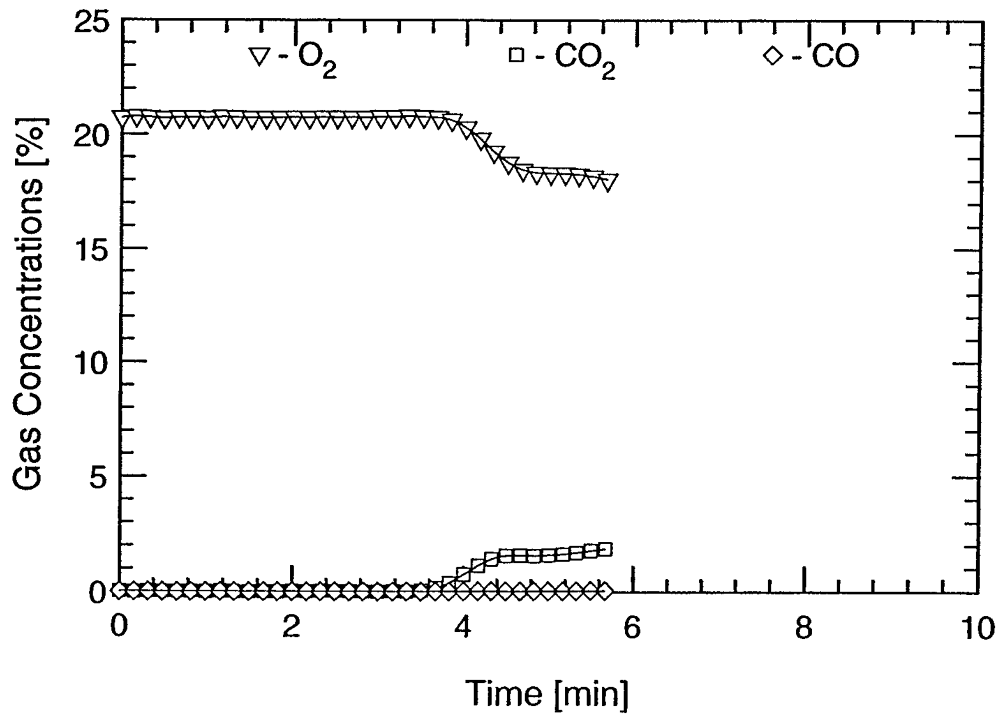


5-35-1

Test #49

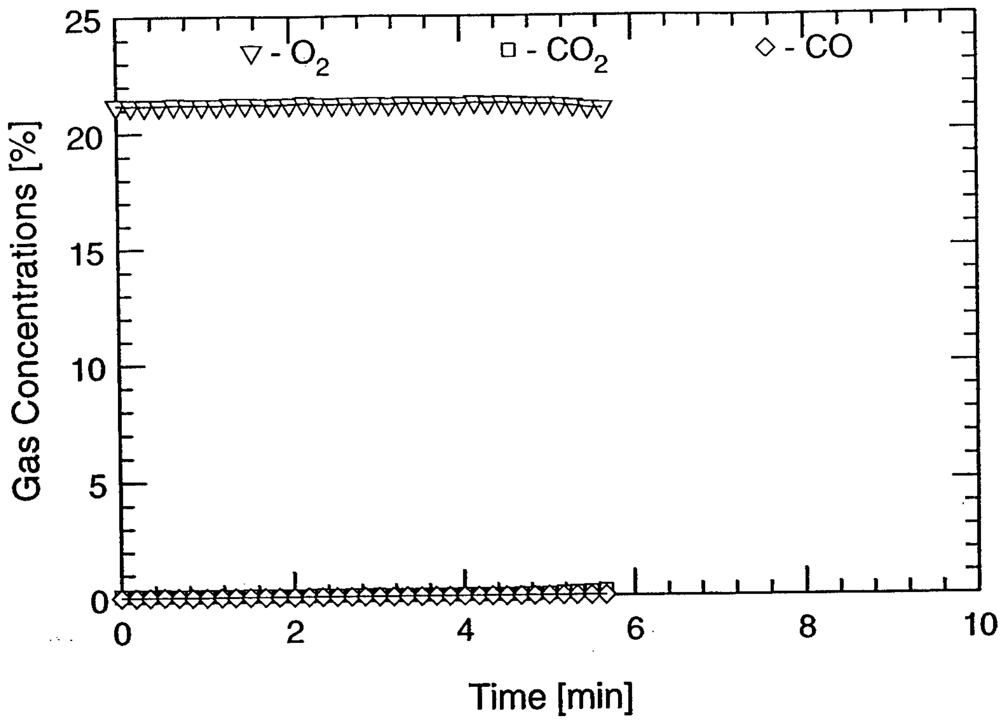


FR 22 - 0.5 m

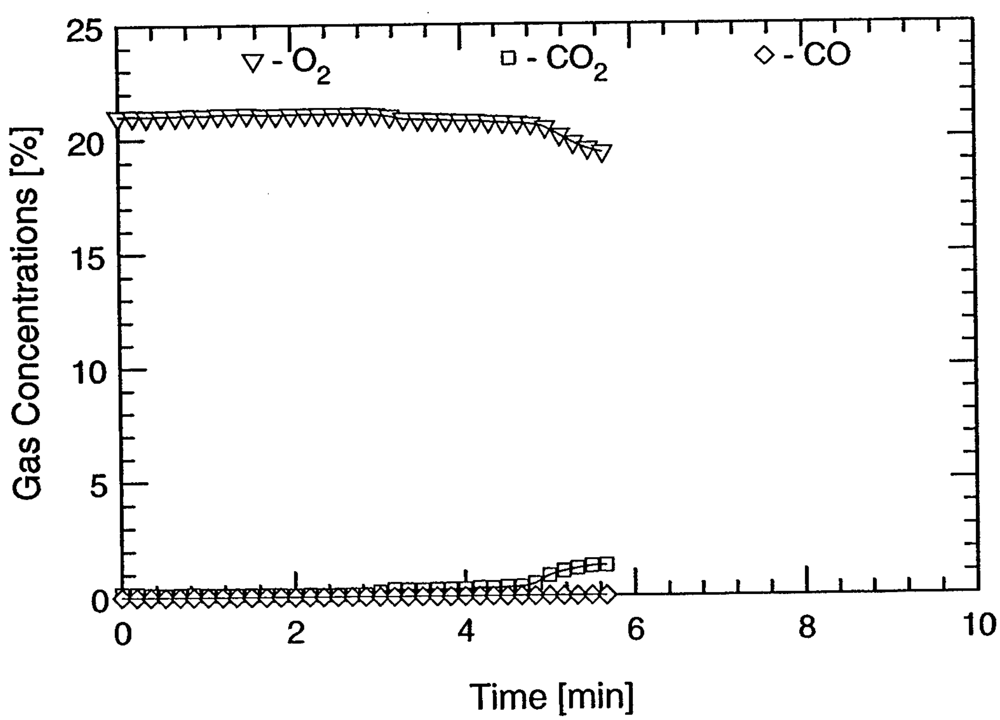


FR 22 - 4.5 m

Test #49

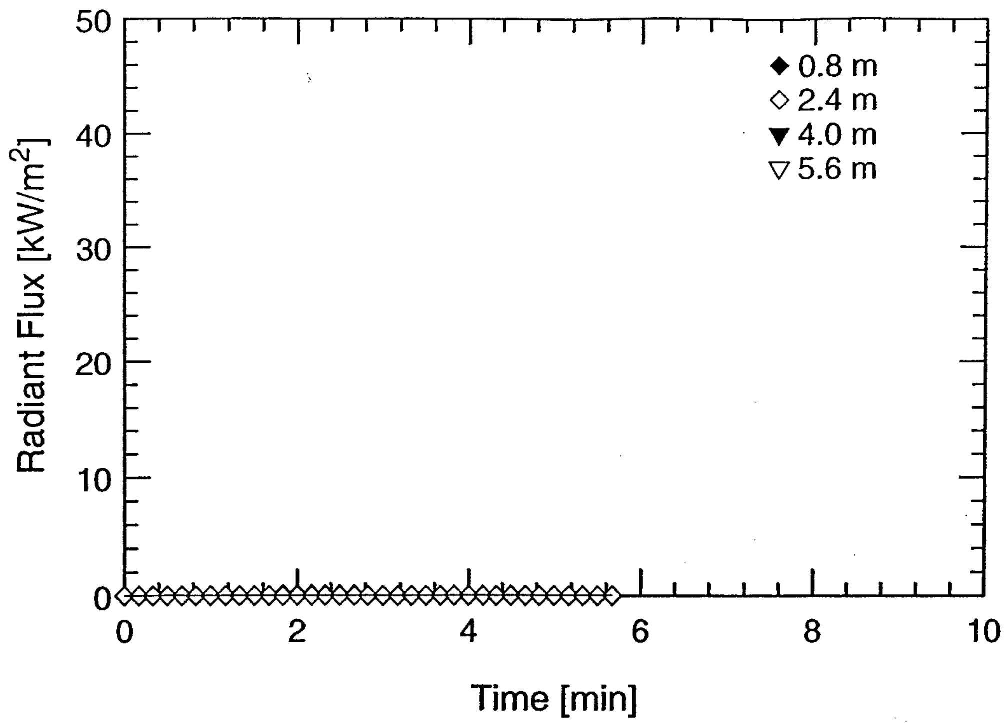


FR 36 - 0.5 m

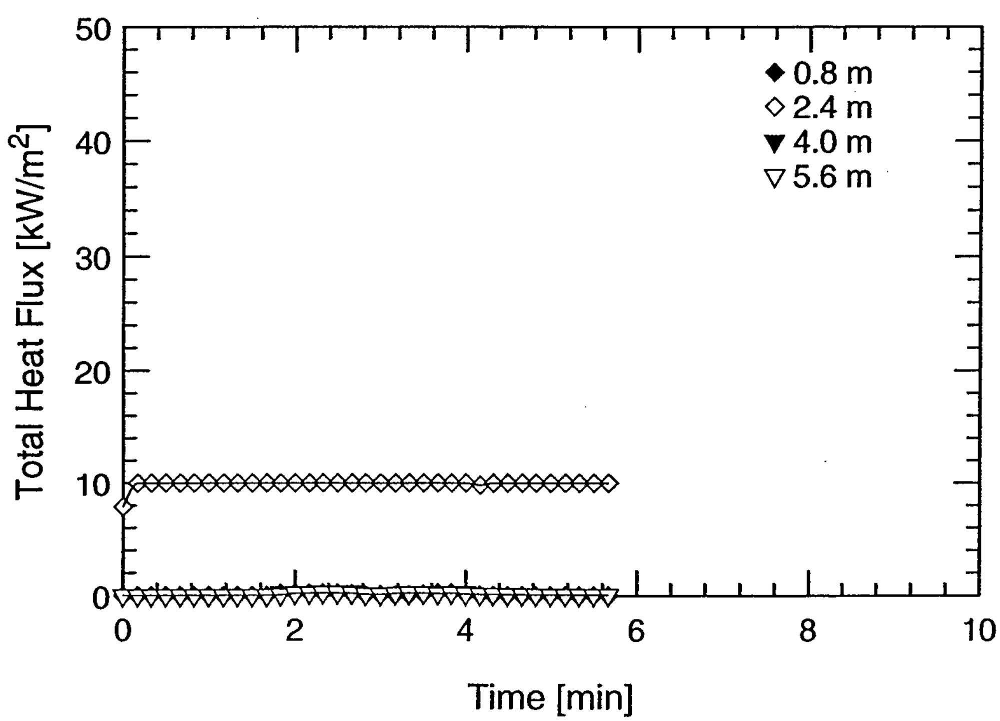


FR 36 - 4.5 m

Test #49

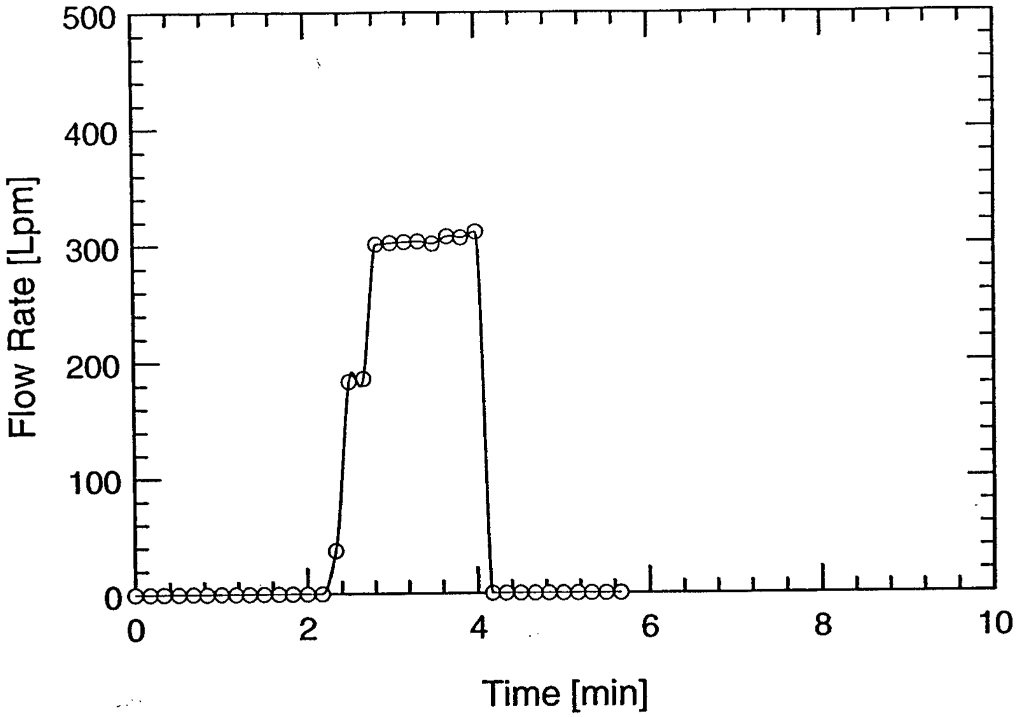


FR 22

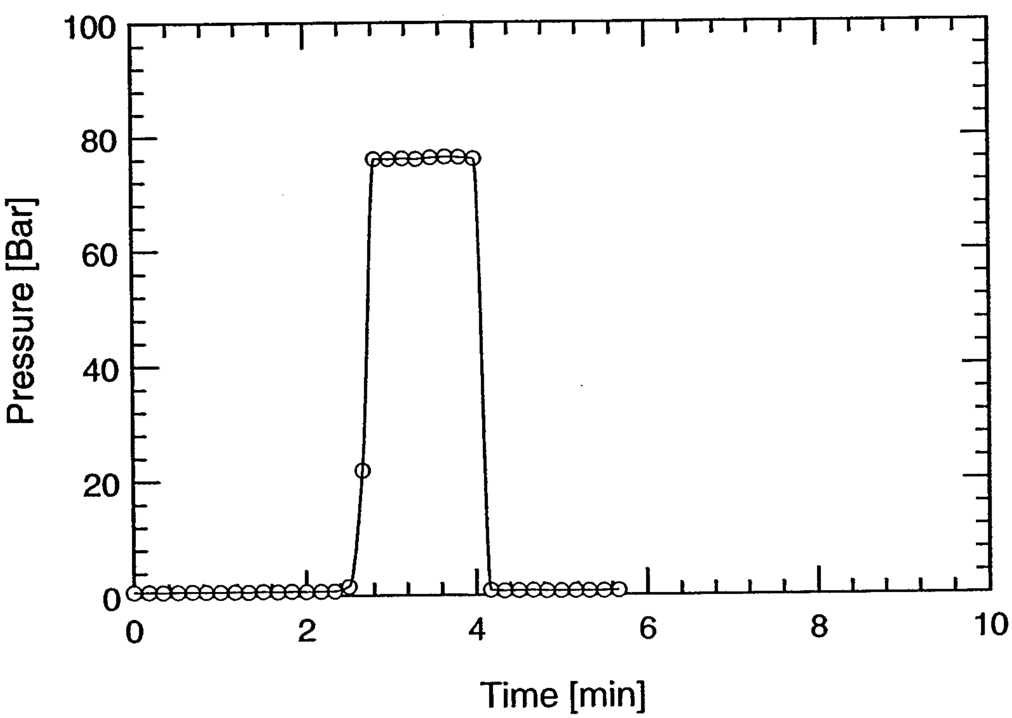


FR 22

Test #49

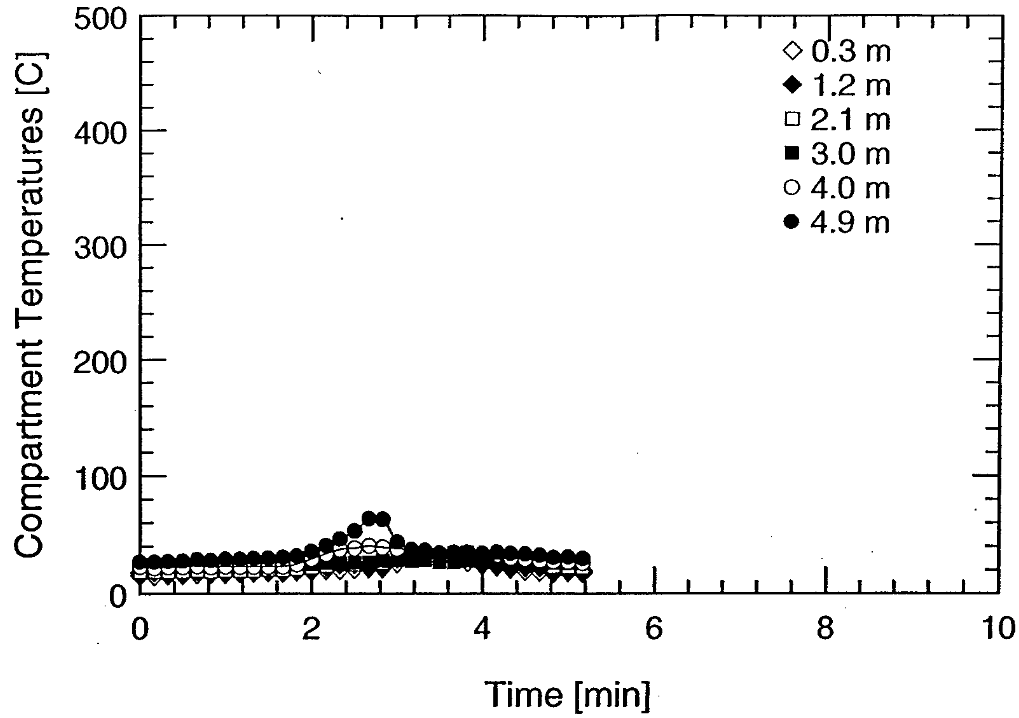


Water Mist System Flow Rate

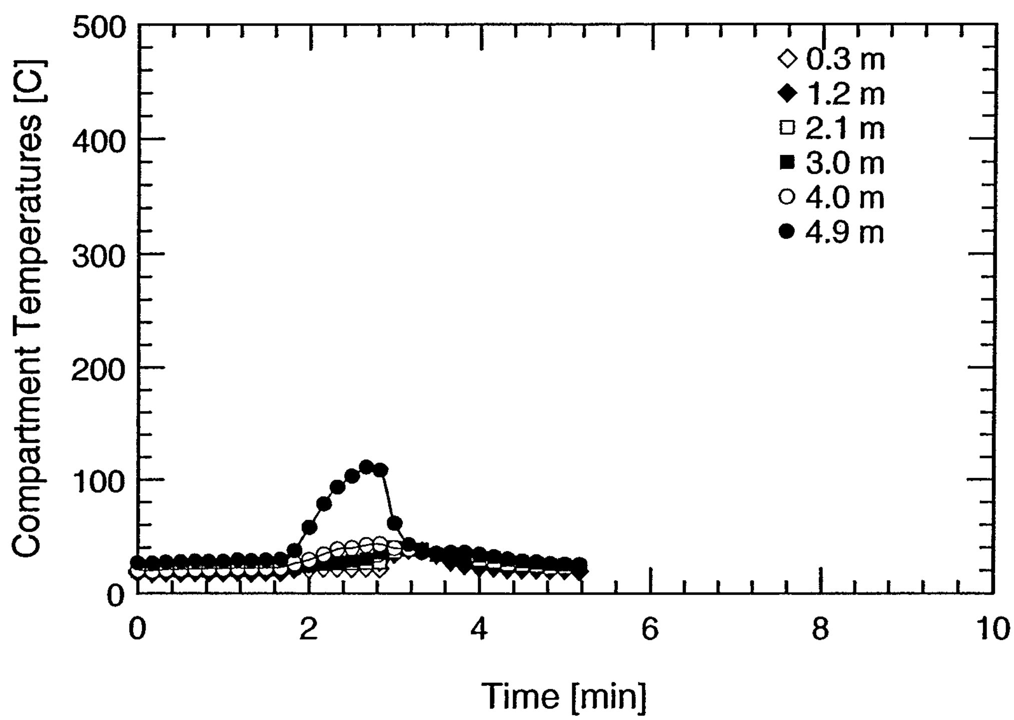


Water Mist System Pressure

Test #49

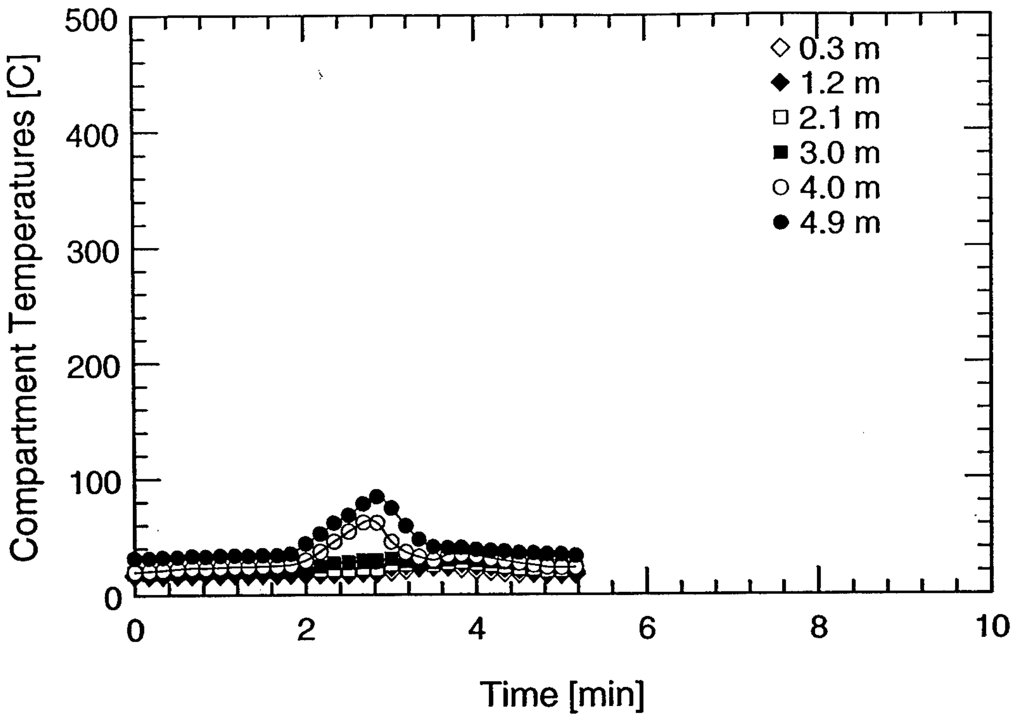


5-22-1

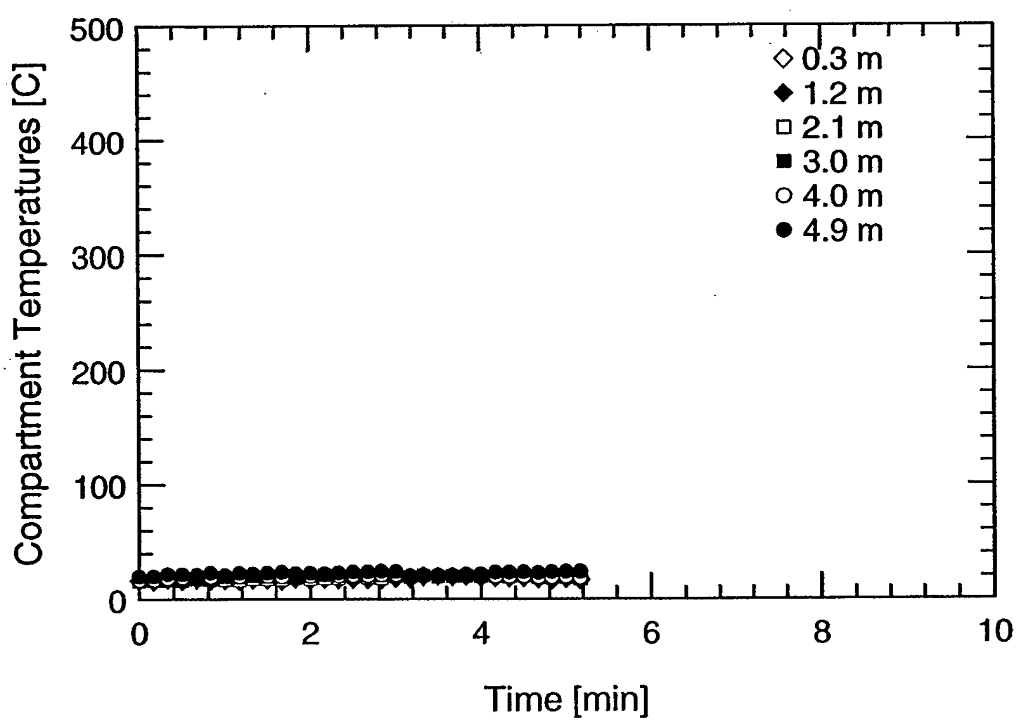


5-27-1

Test #50

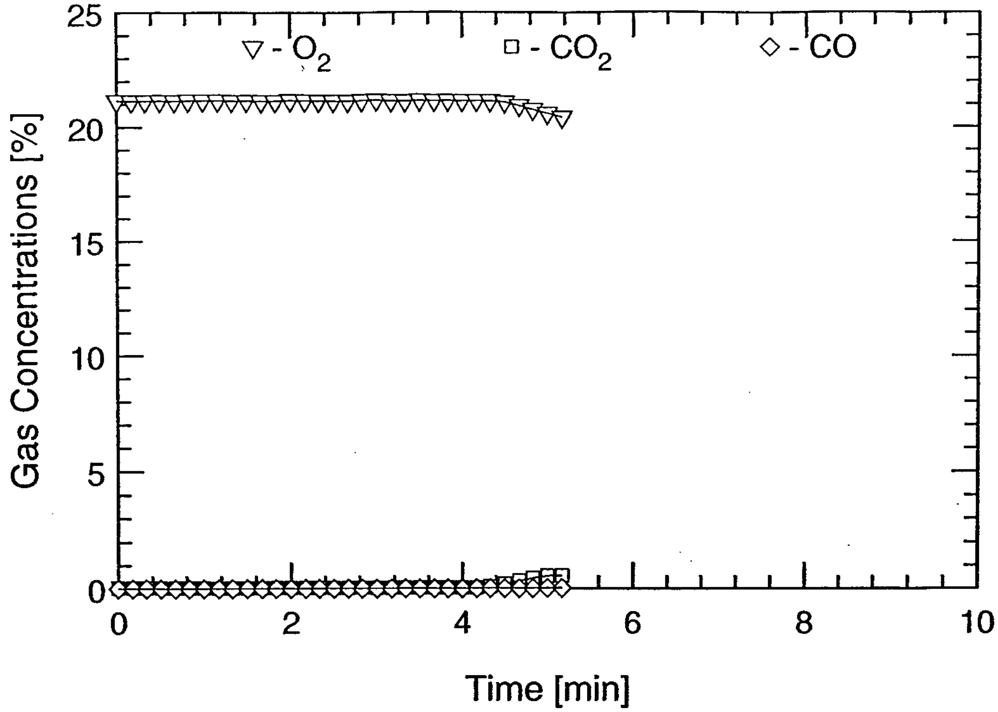


5-27-2

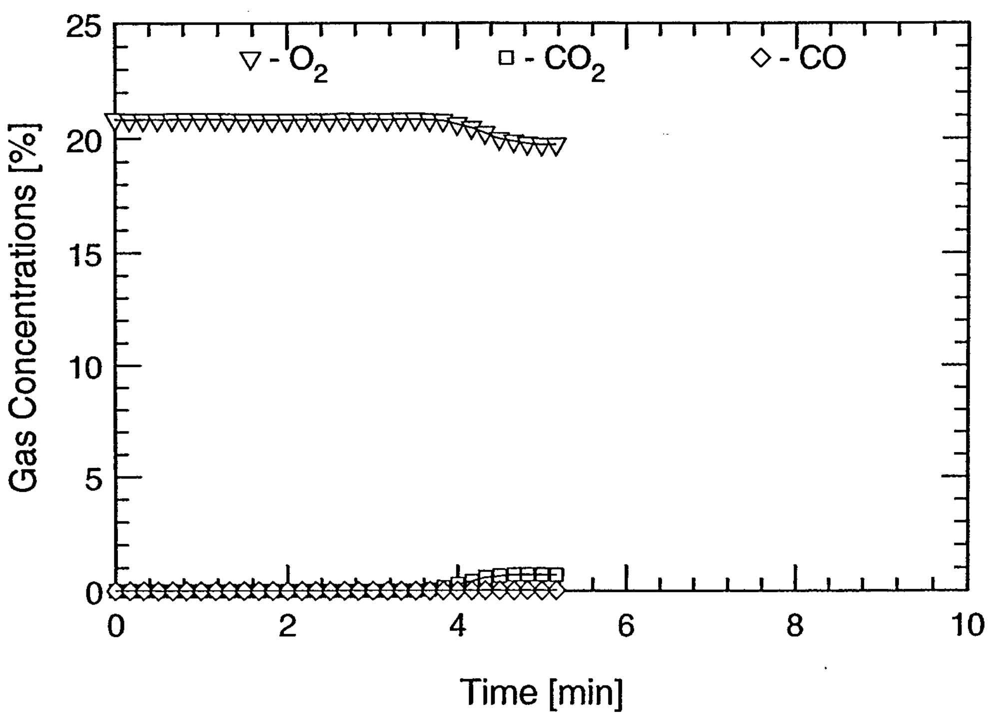


5-35-1

Test #50

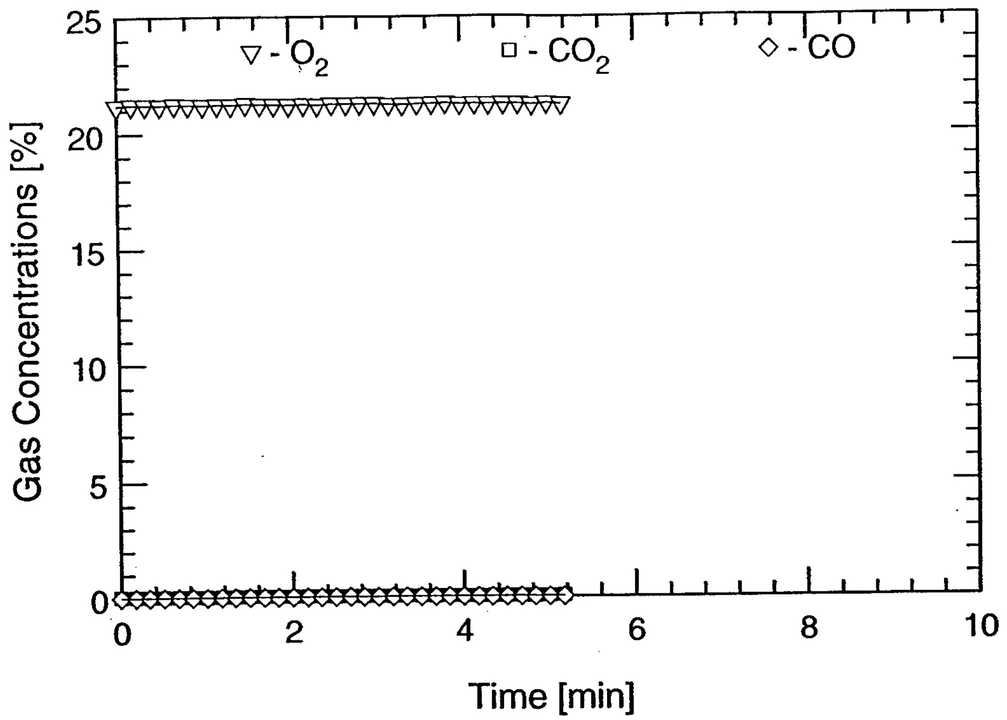


FR 22 - 0.5 m

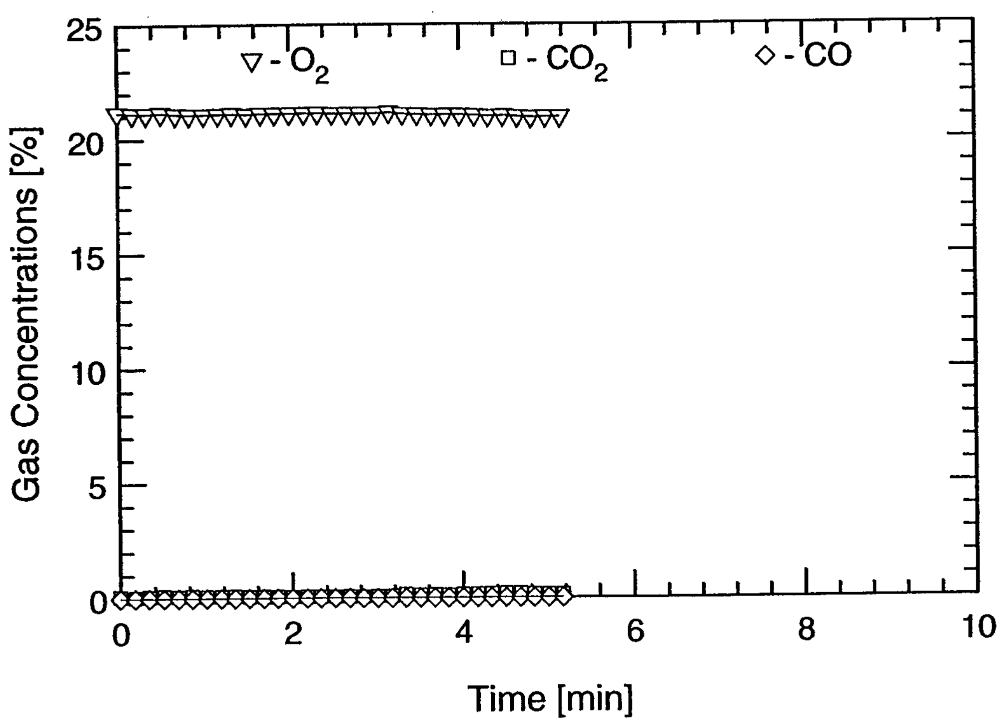


FR 22 - 4.5 m

Test #50

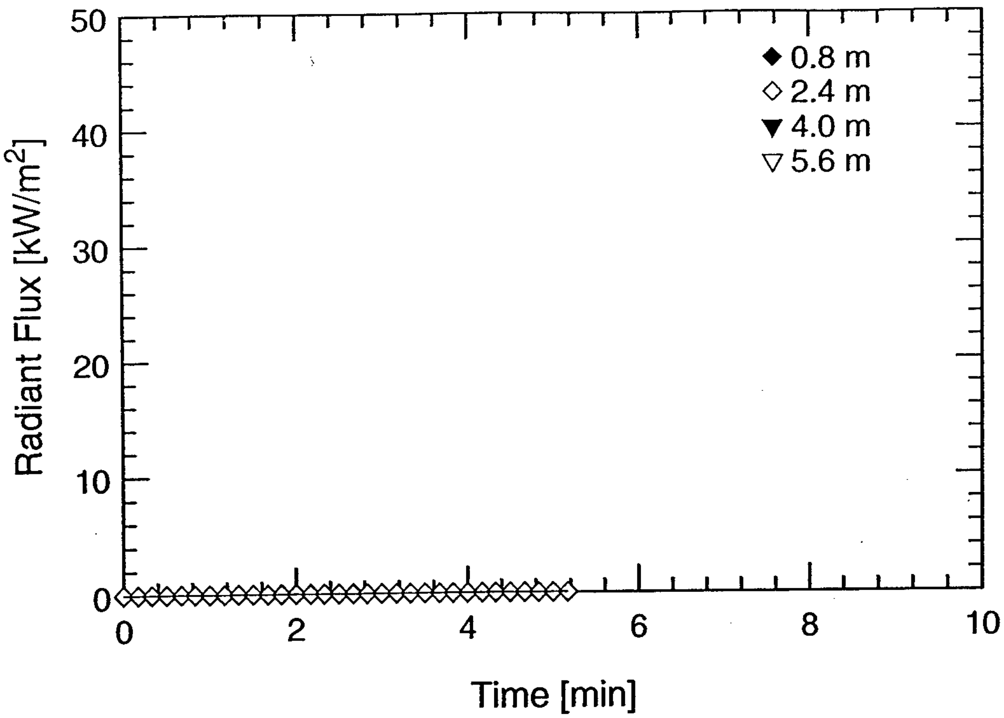


FR 36 - 0.5 m

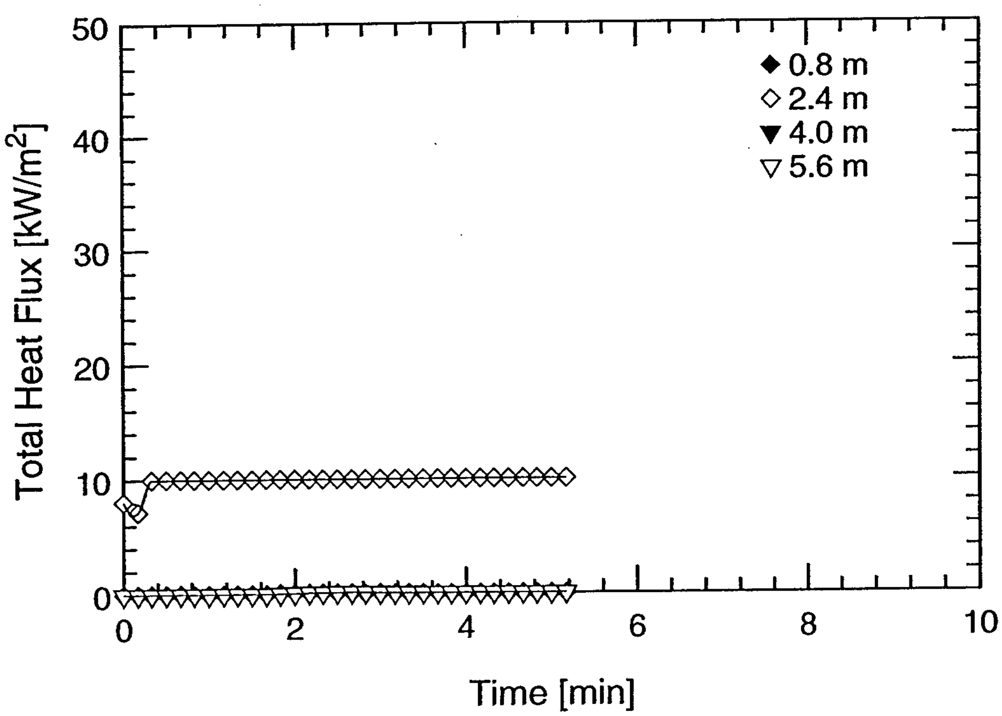


FR 36 - 4.5 m

Test #50

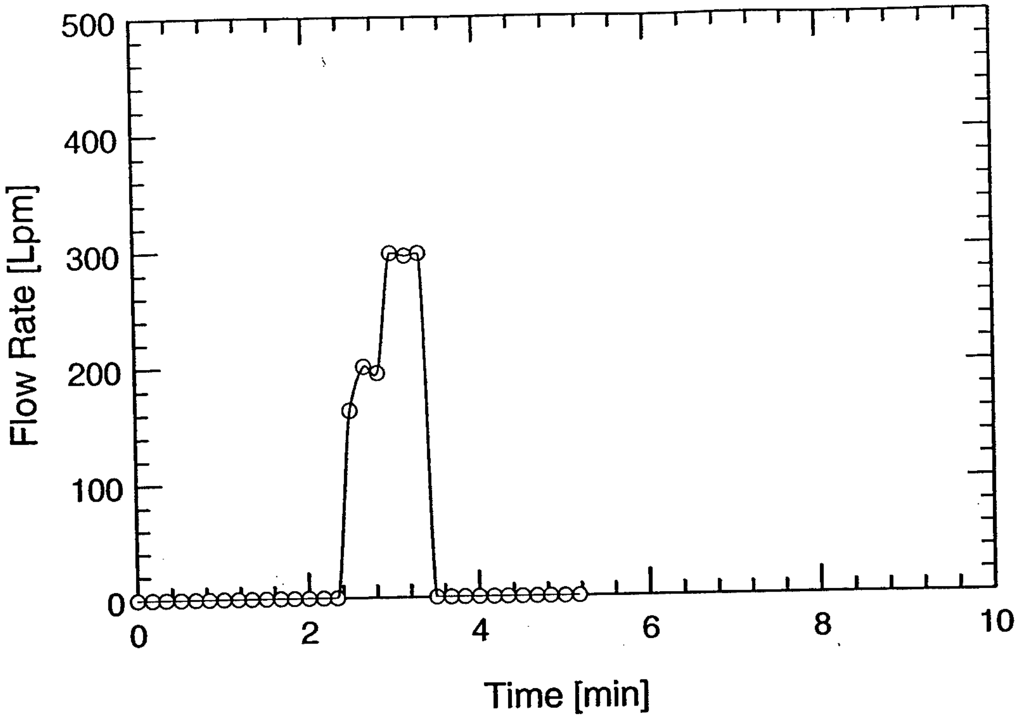


FR 22

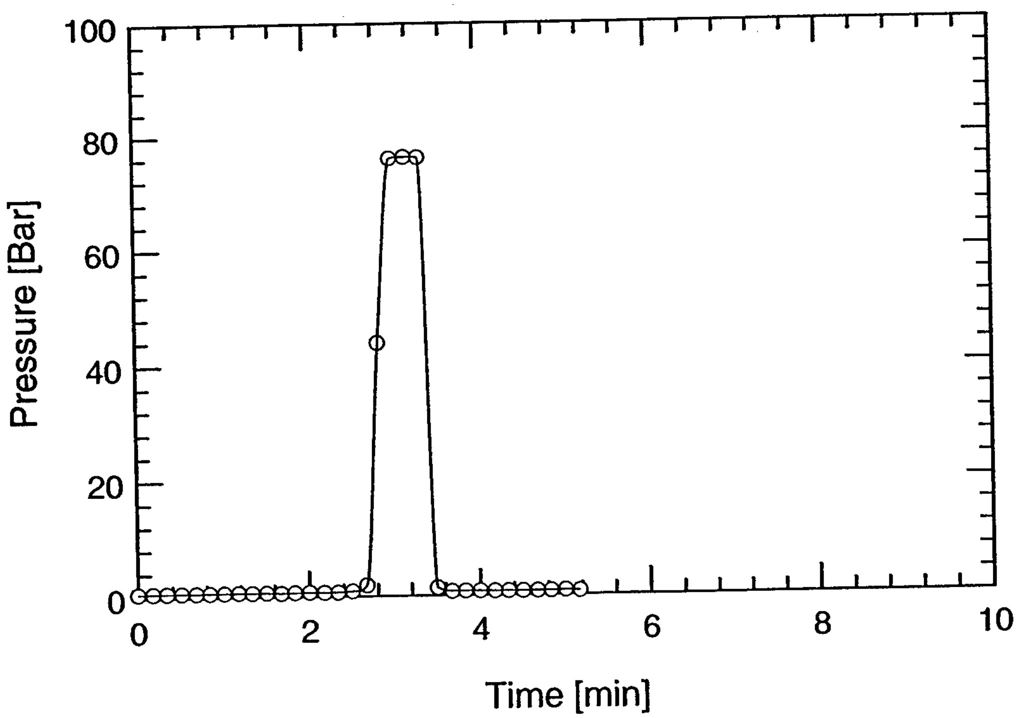


FR 22

Test #50

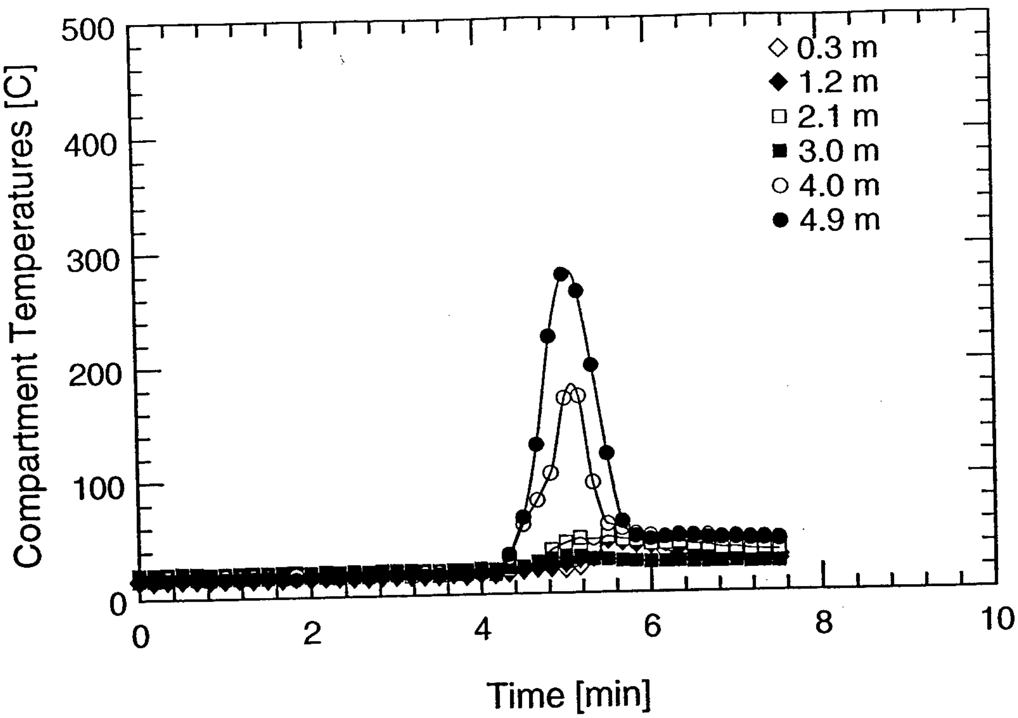


Water Mist System Flow Rate

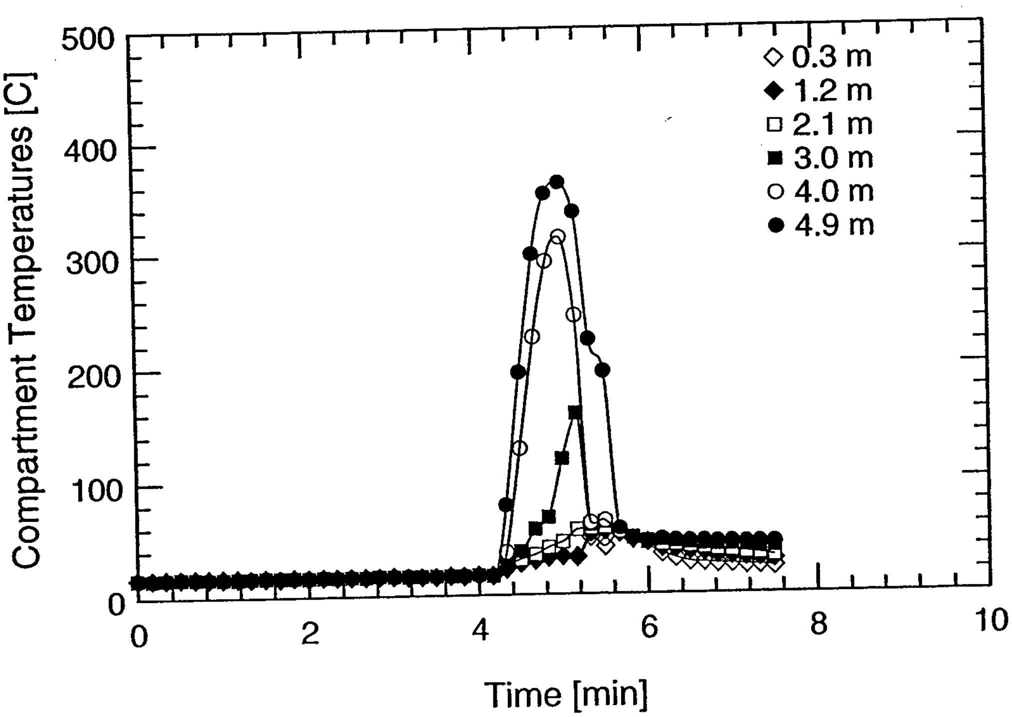


Water Mist System Pressure

Test #50

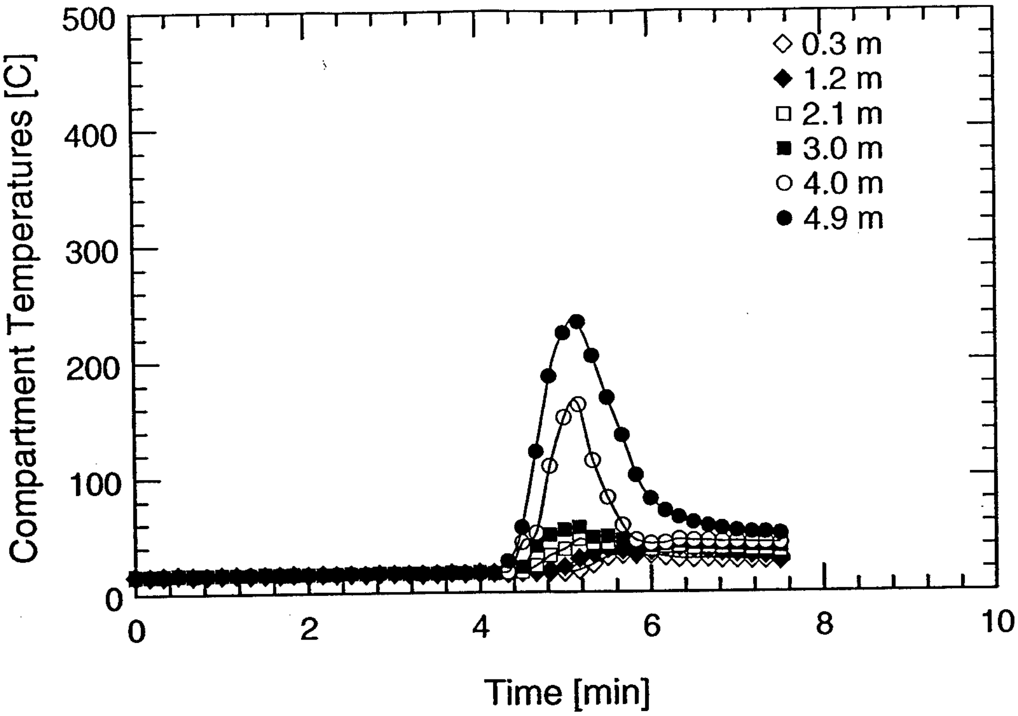


5-22-1

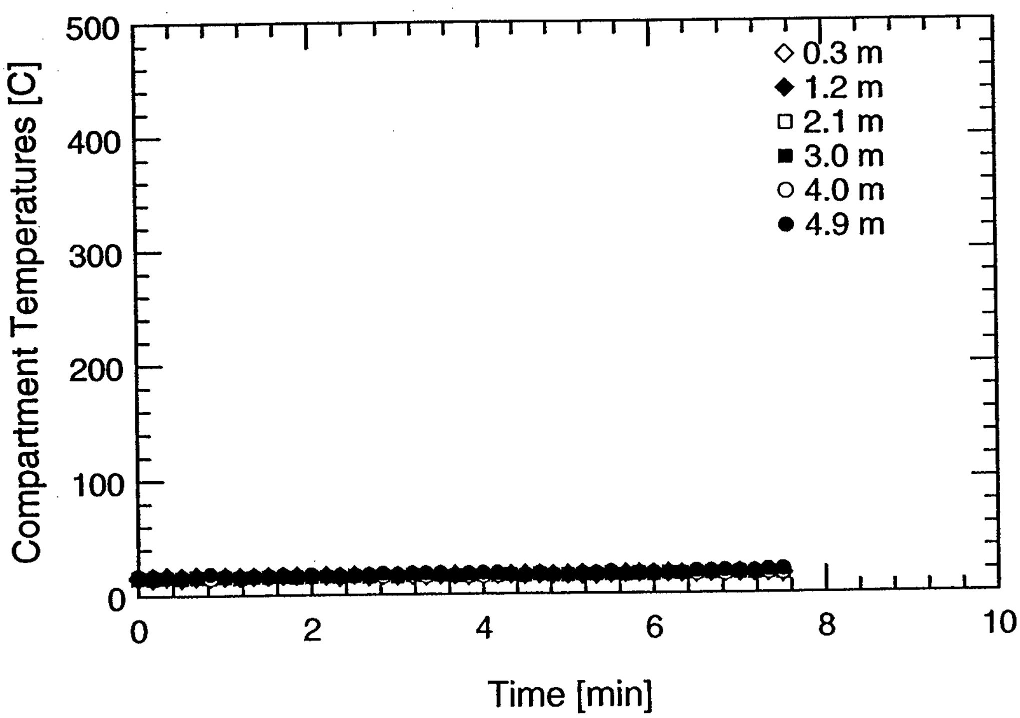


5-27-1

Test #51

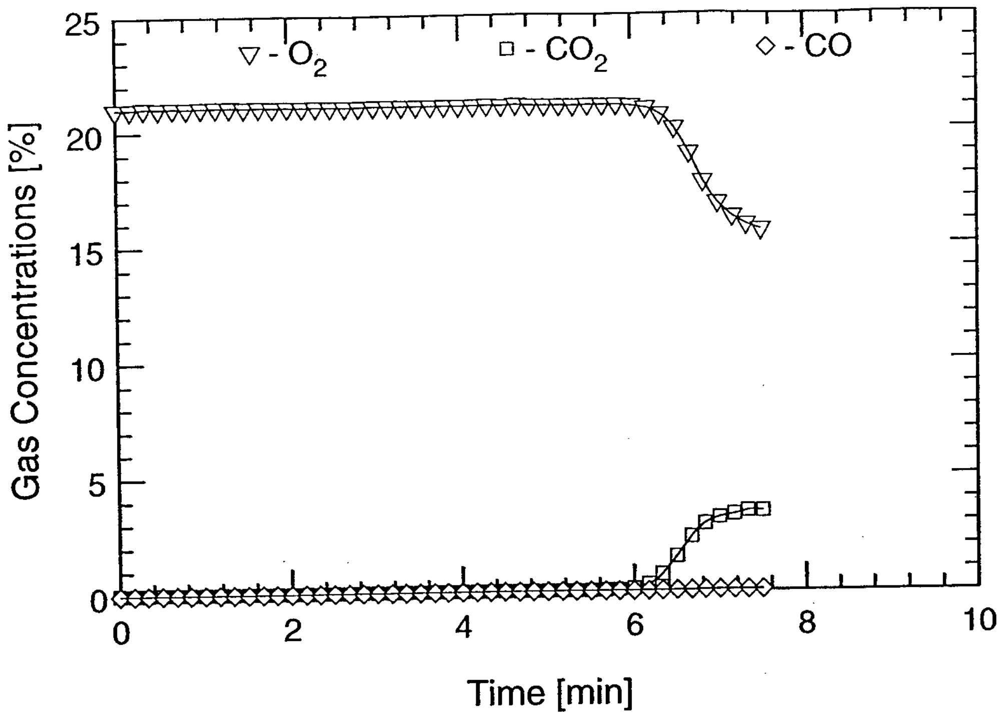


5-27-2

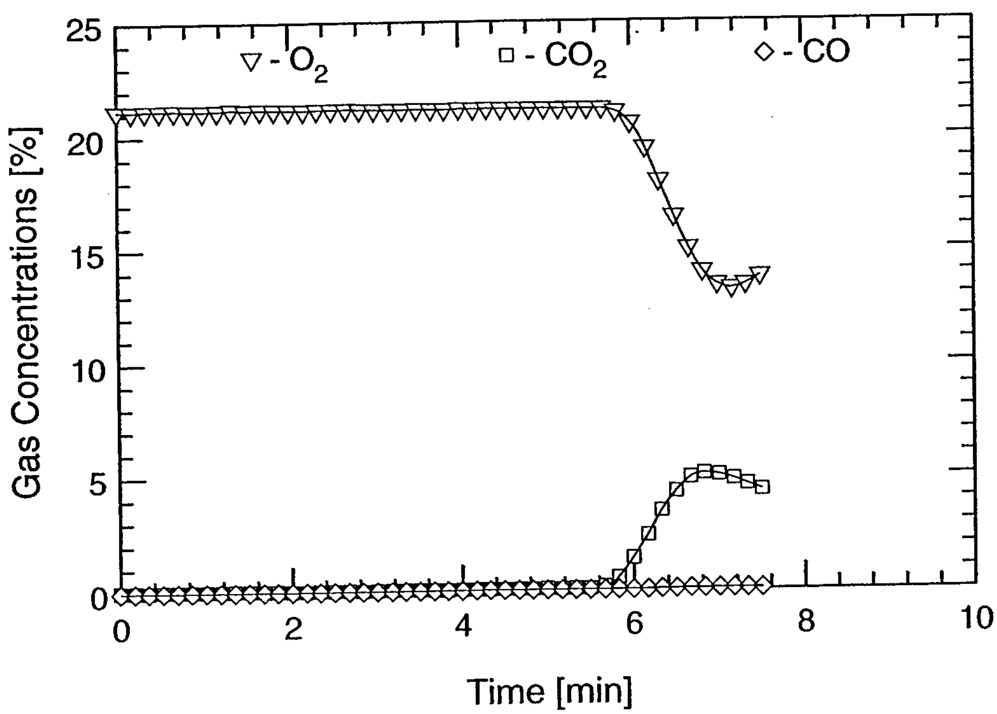


5-35-1

Test #51

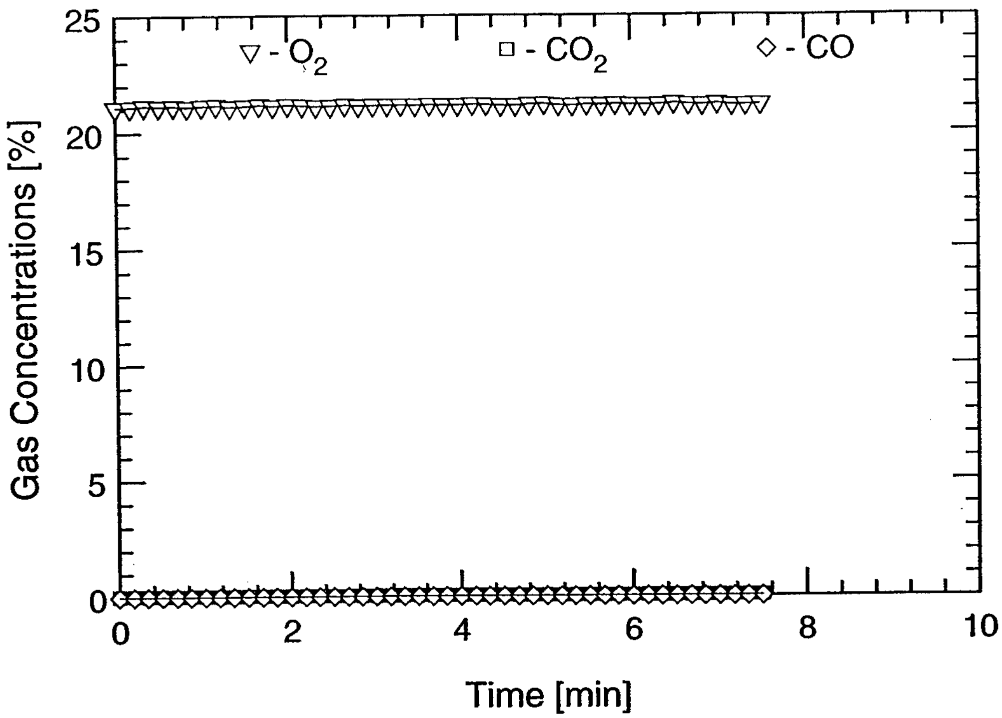


FR 22 - 0.5 m

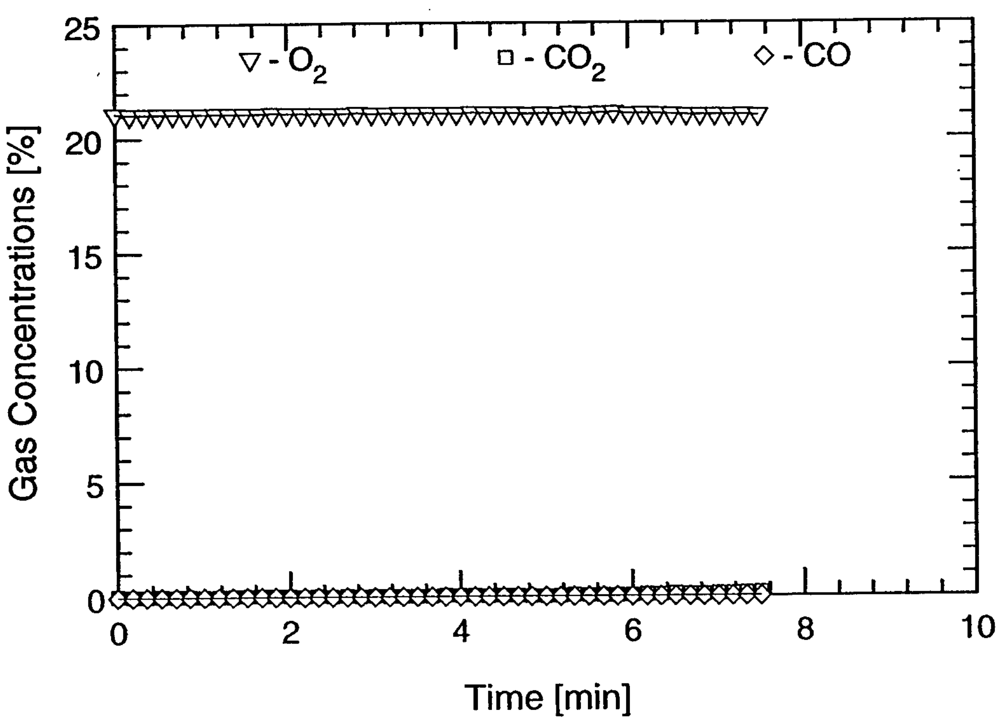


FR 22 - 4.5 m

Test #51

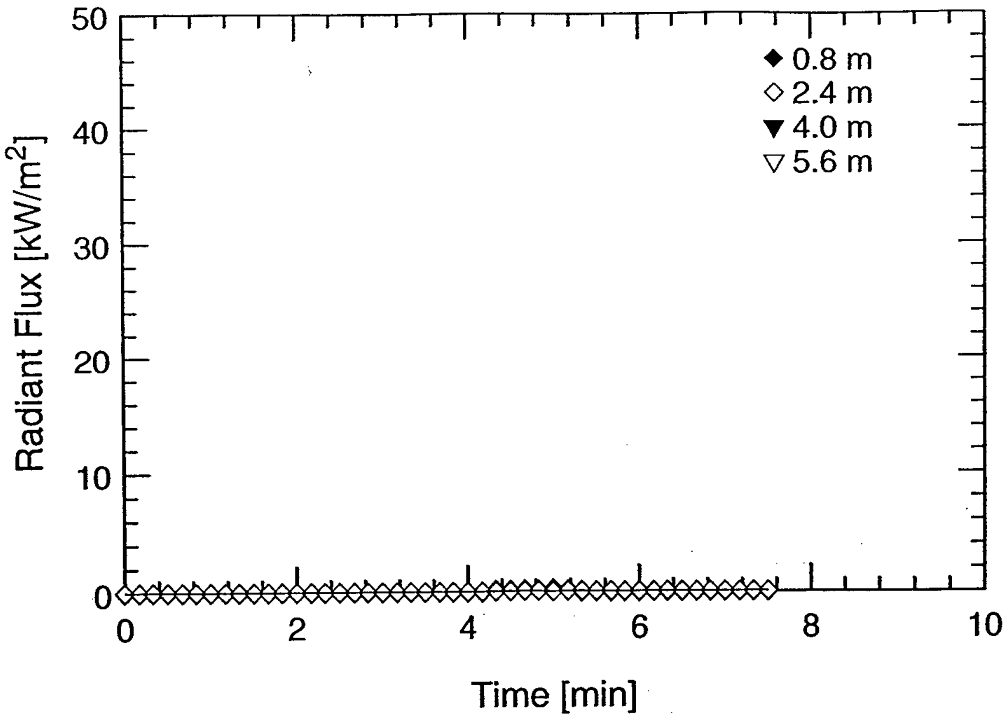


FR 36 - 0.5 m

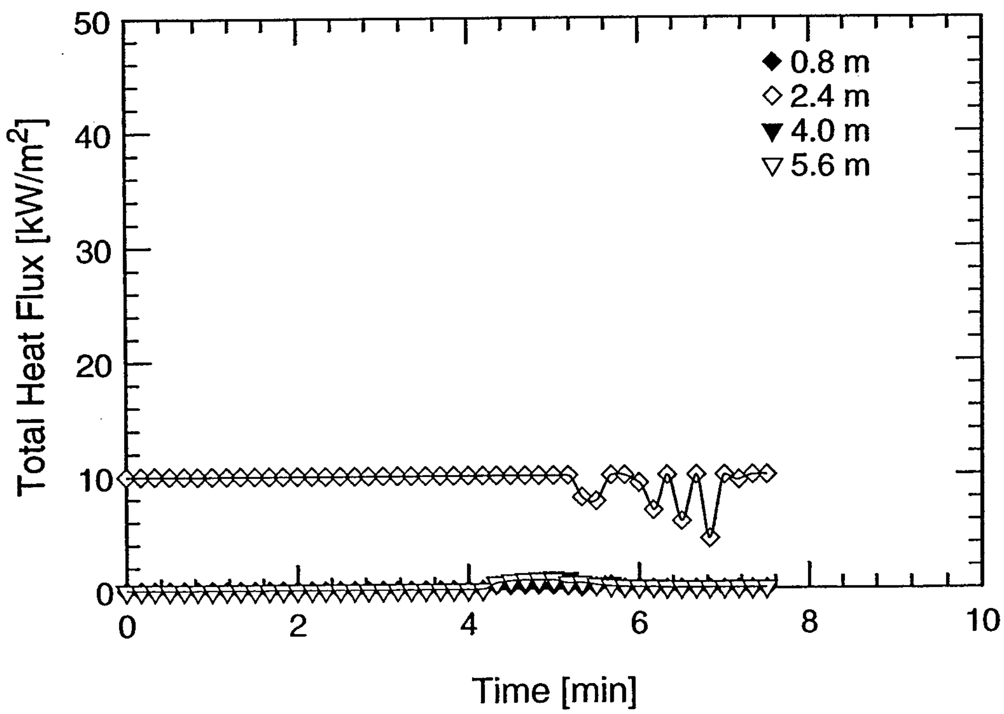


FR 36 - 4.5 m

Test #51

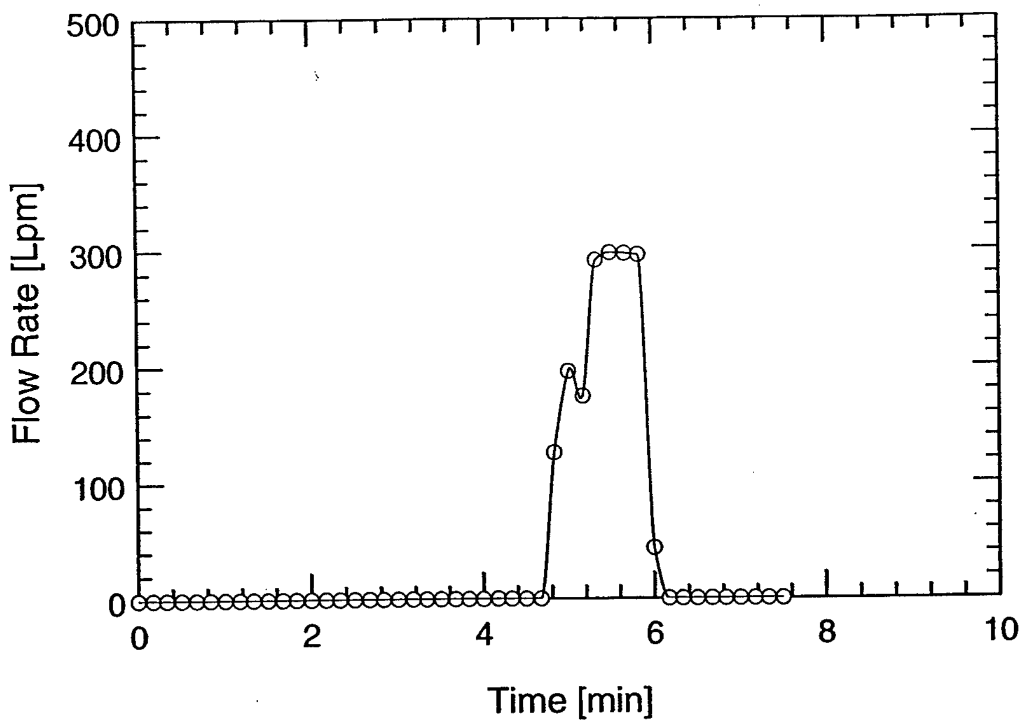


FR 22

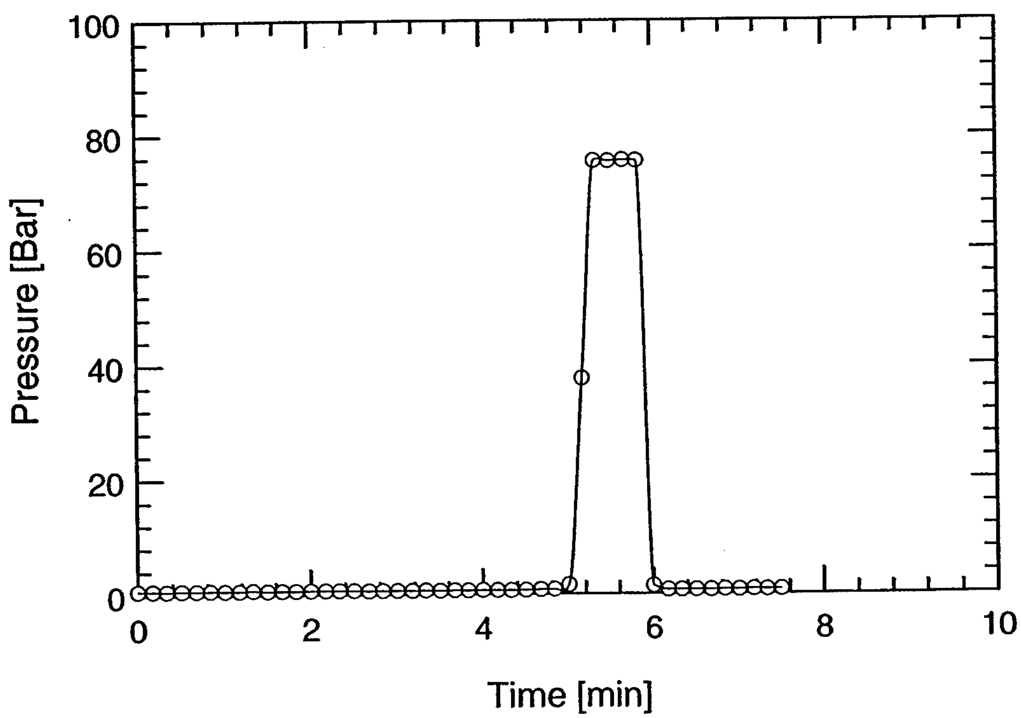


FR 22

Test #51

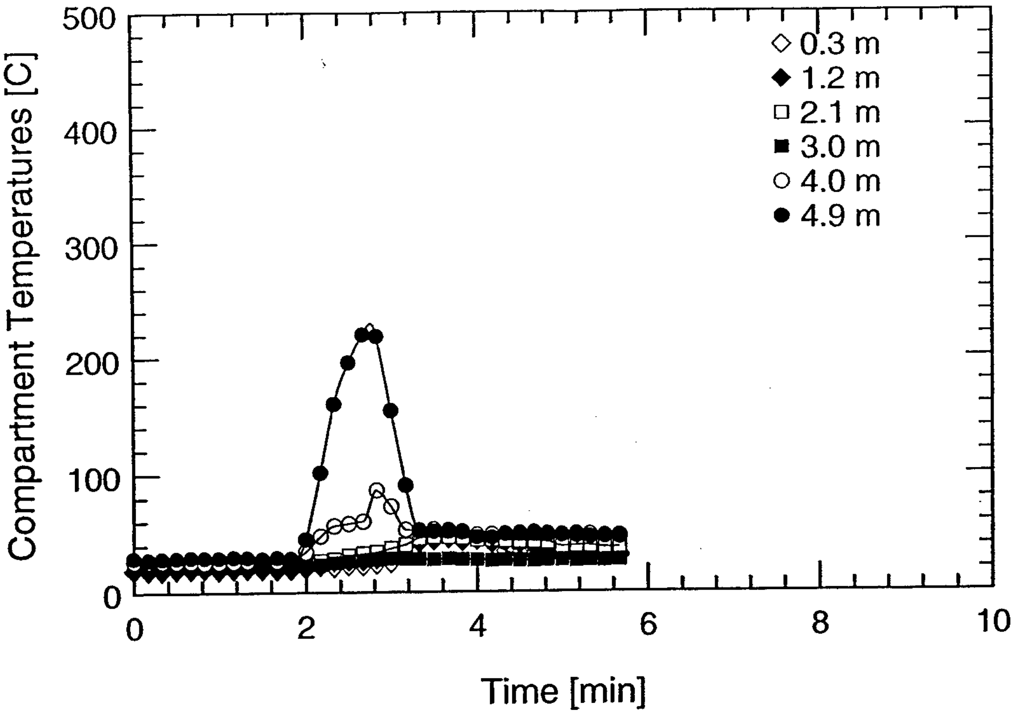


Water Mist System Flow Rate

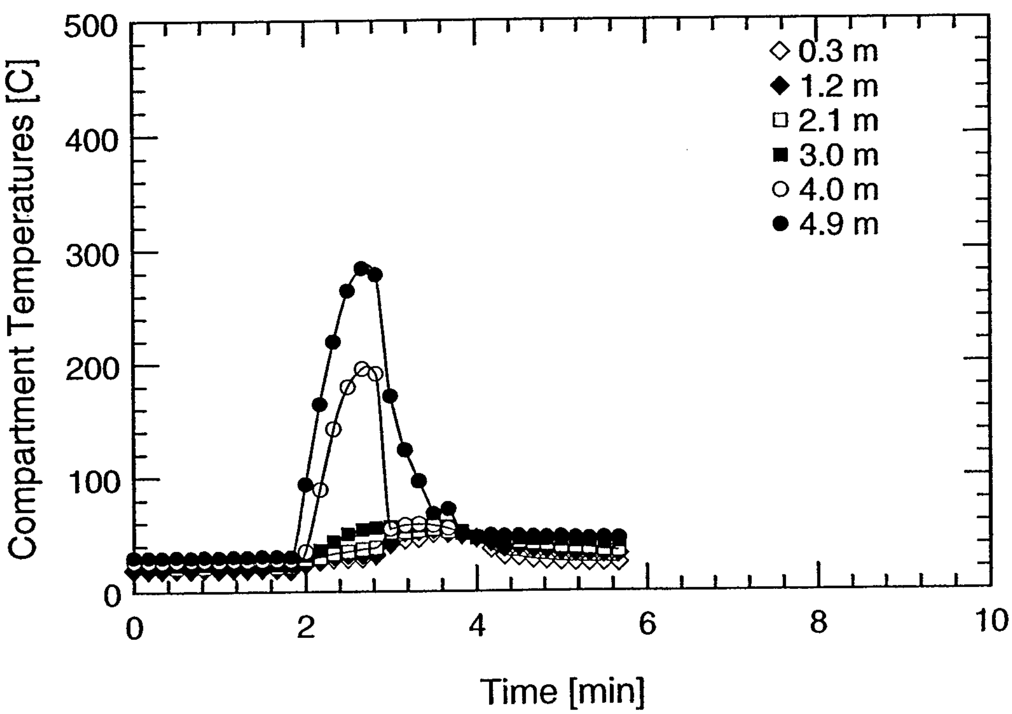


Water Mist System Pressure

Test #51

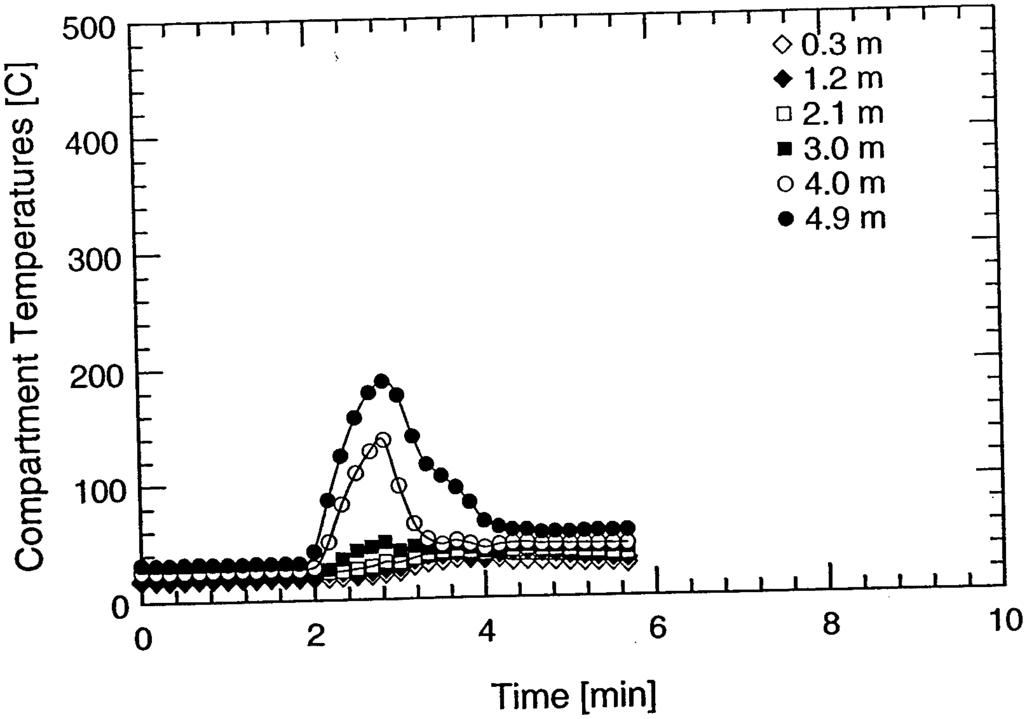


5-22-1

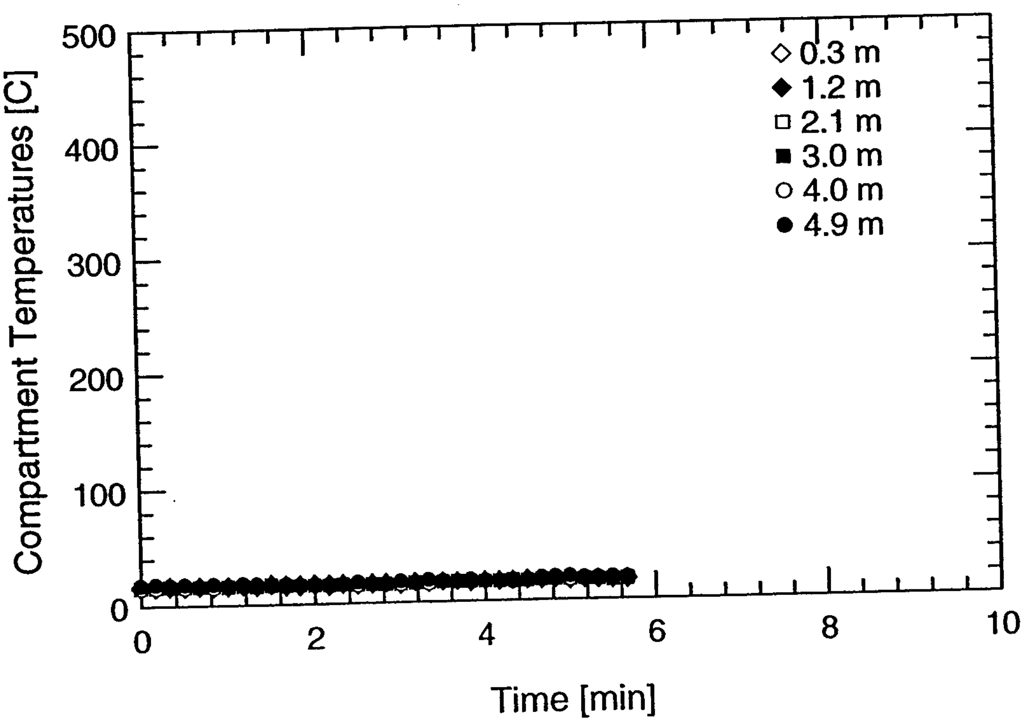


5-27-1

Test #52

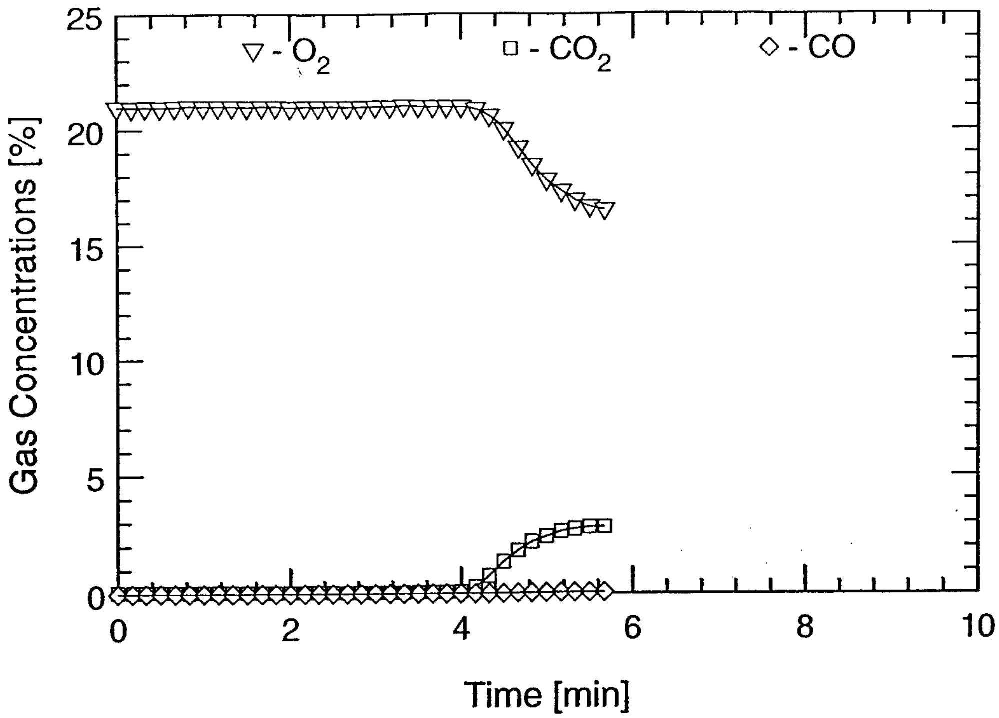


5-27-2

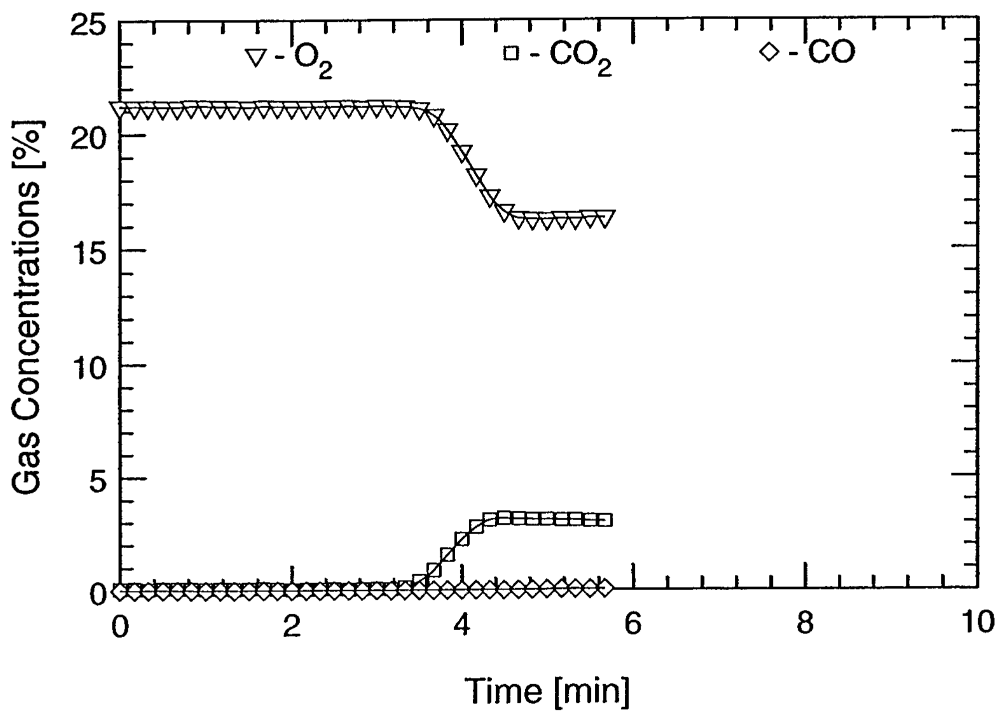


5-35-1

Test #52

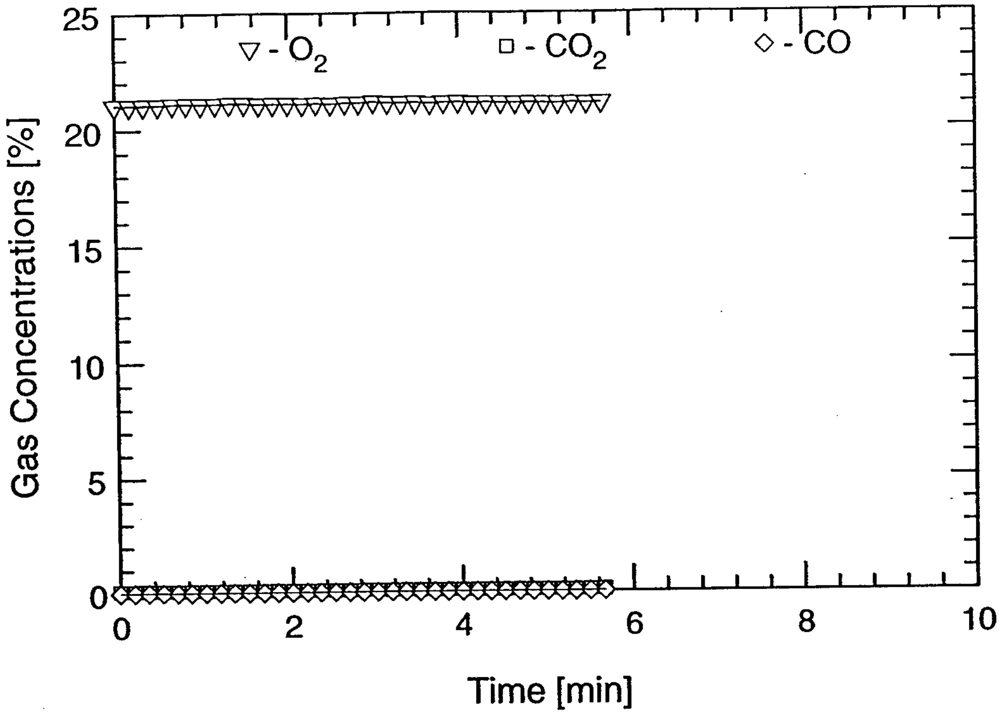


FR 22 - 0.5 m

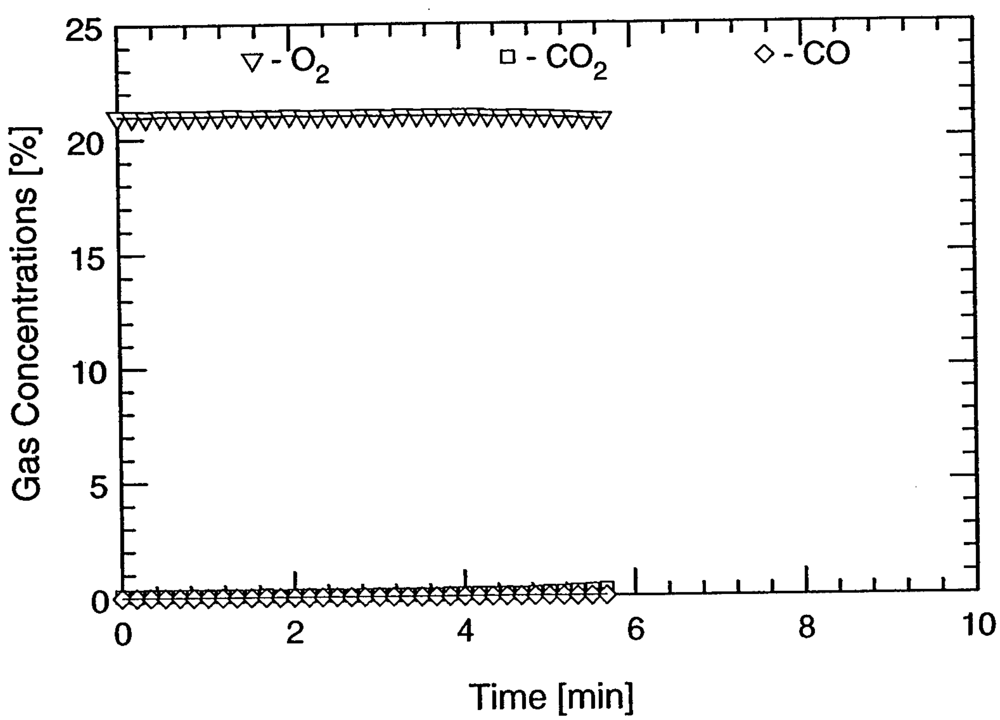


FR 22 - 4.5 m

Test #52

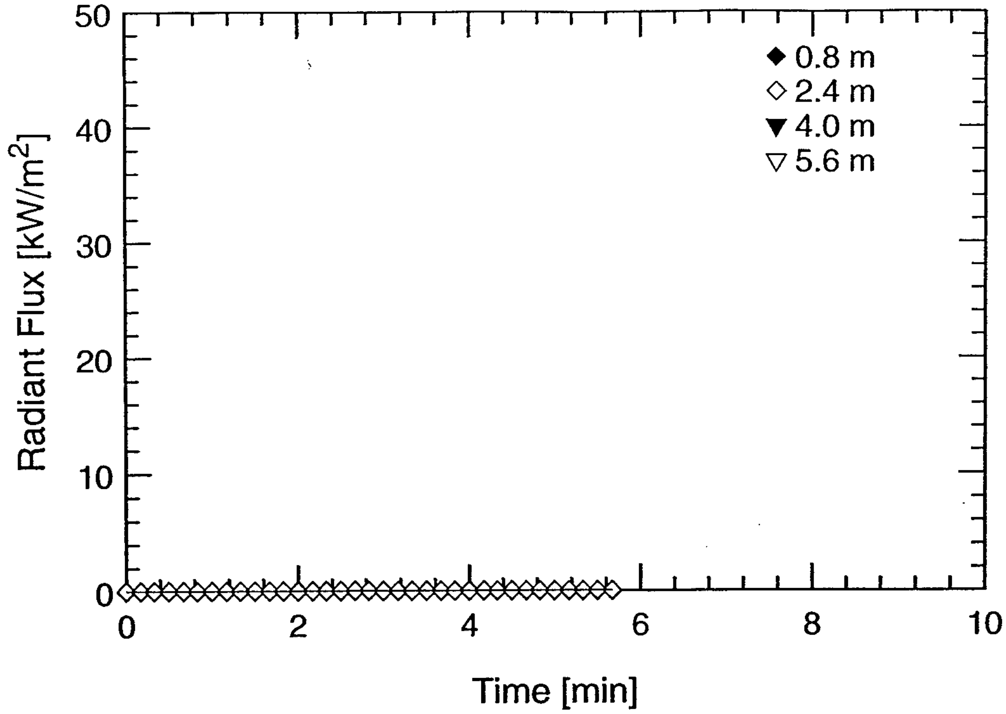


FR 36 - 0.5 m

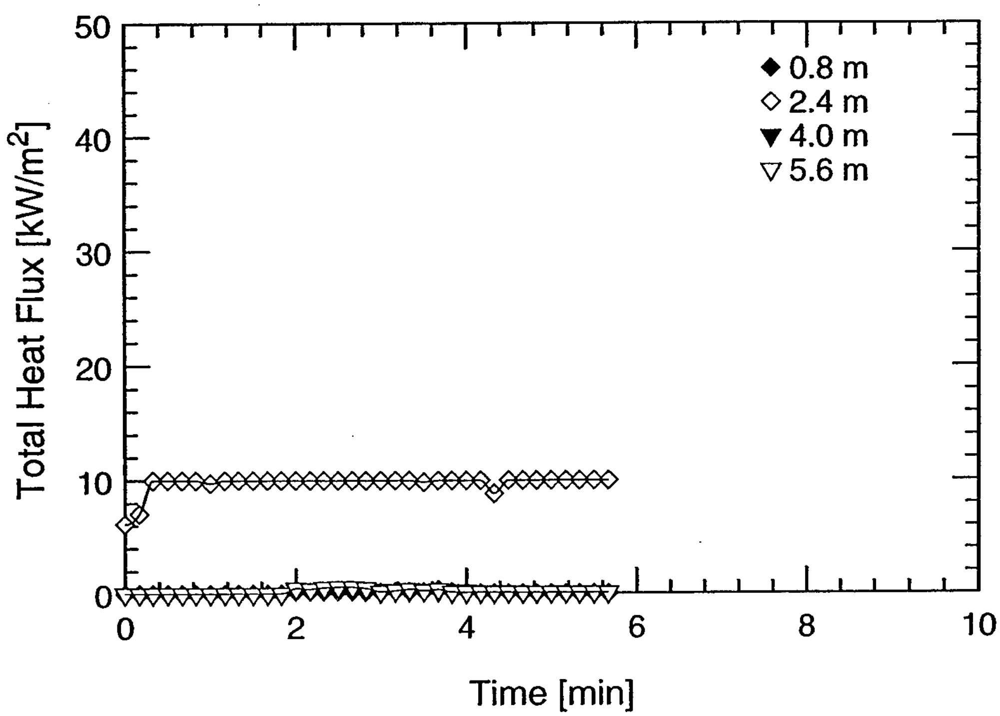


FR 36 - 4.5 m

Test #52

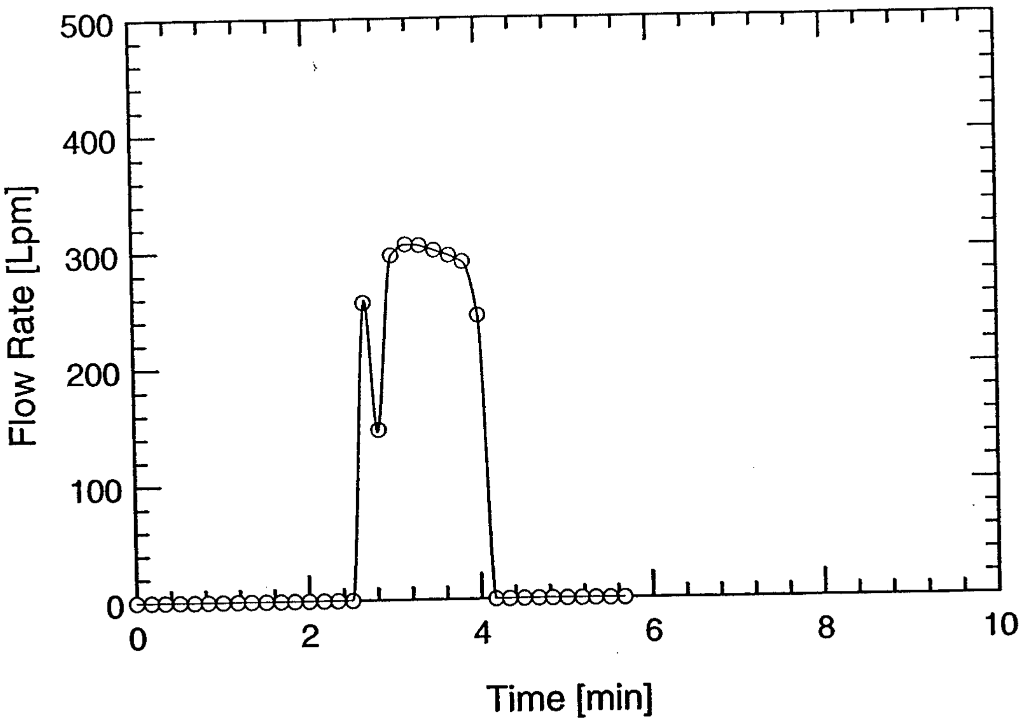


FR 22

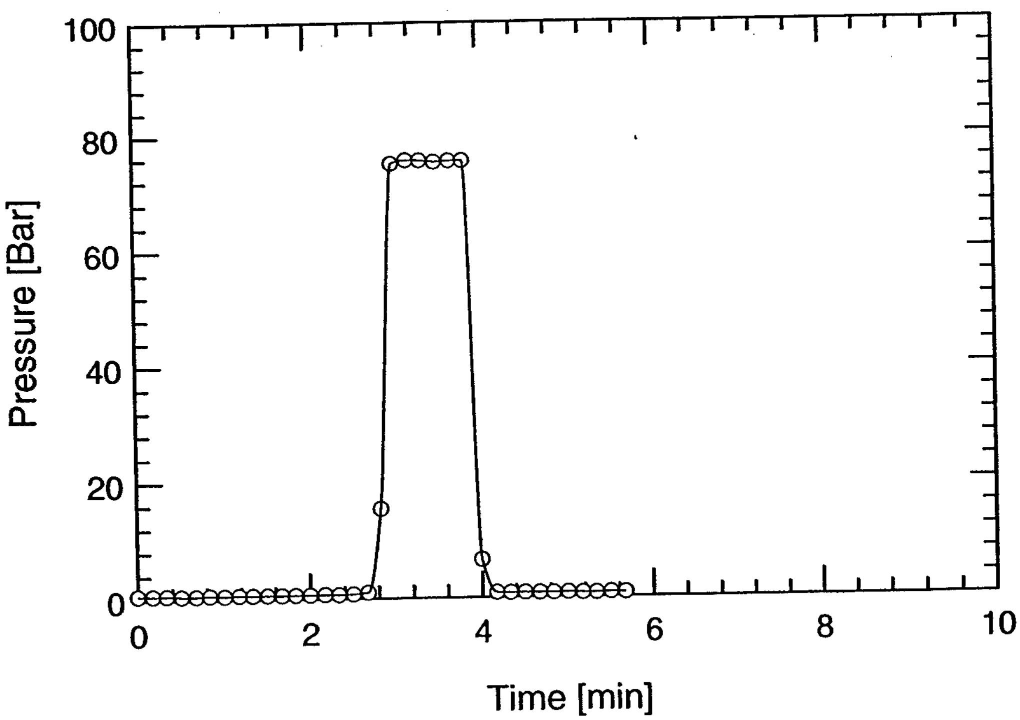


FR 22

Test #52

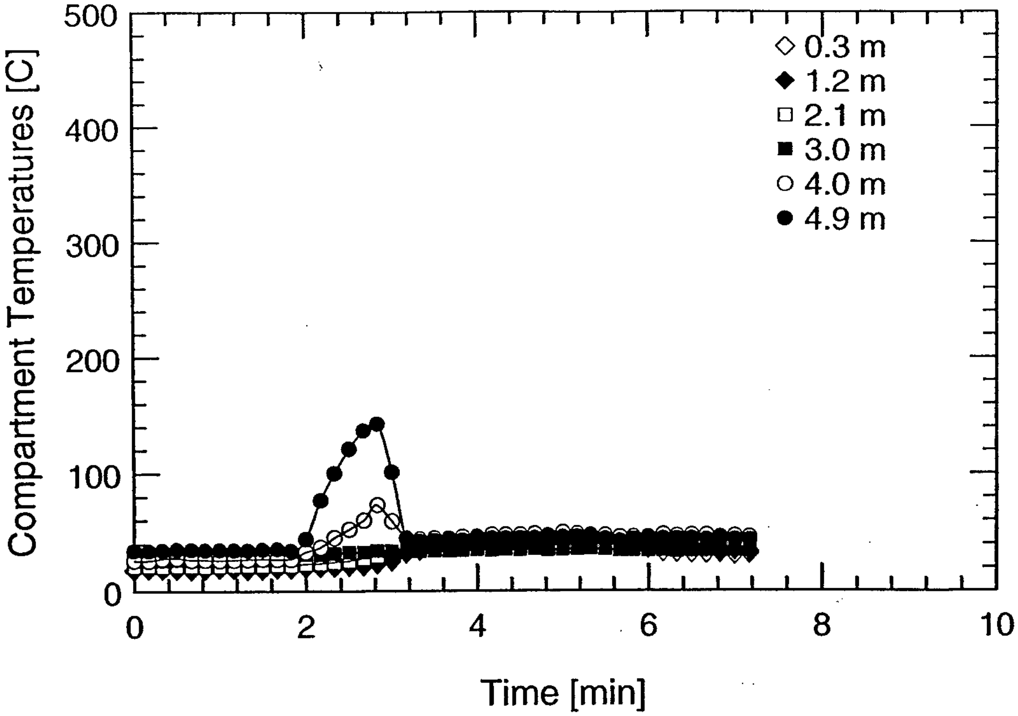


Water Mist System Flow Rate

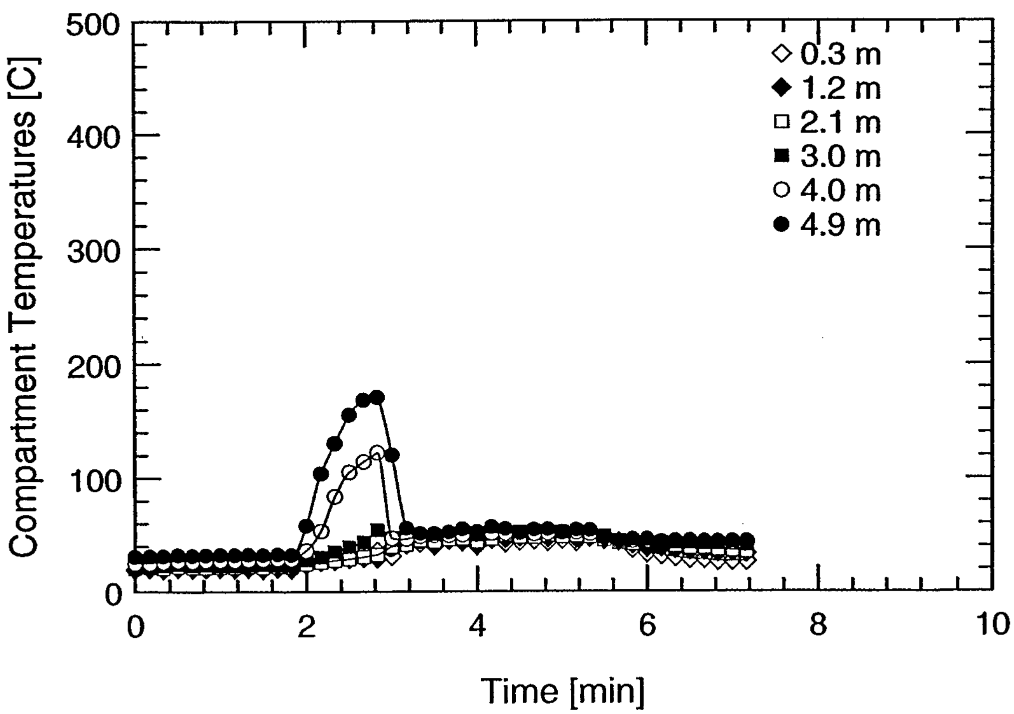


Water Mist System Pressure

Test #52

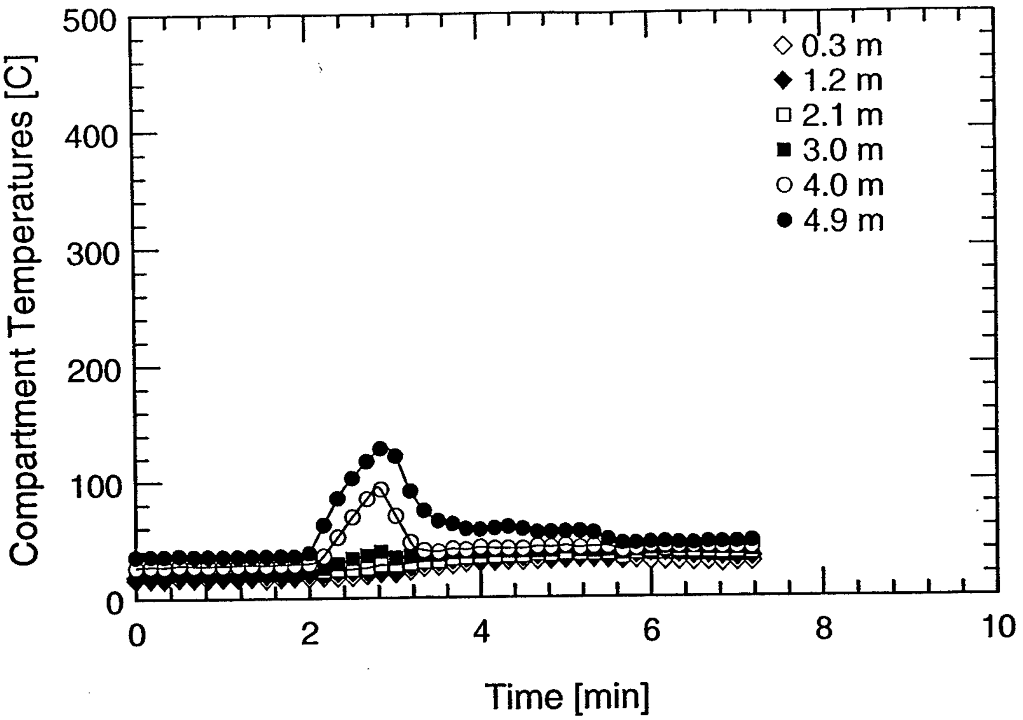


5-22-1

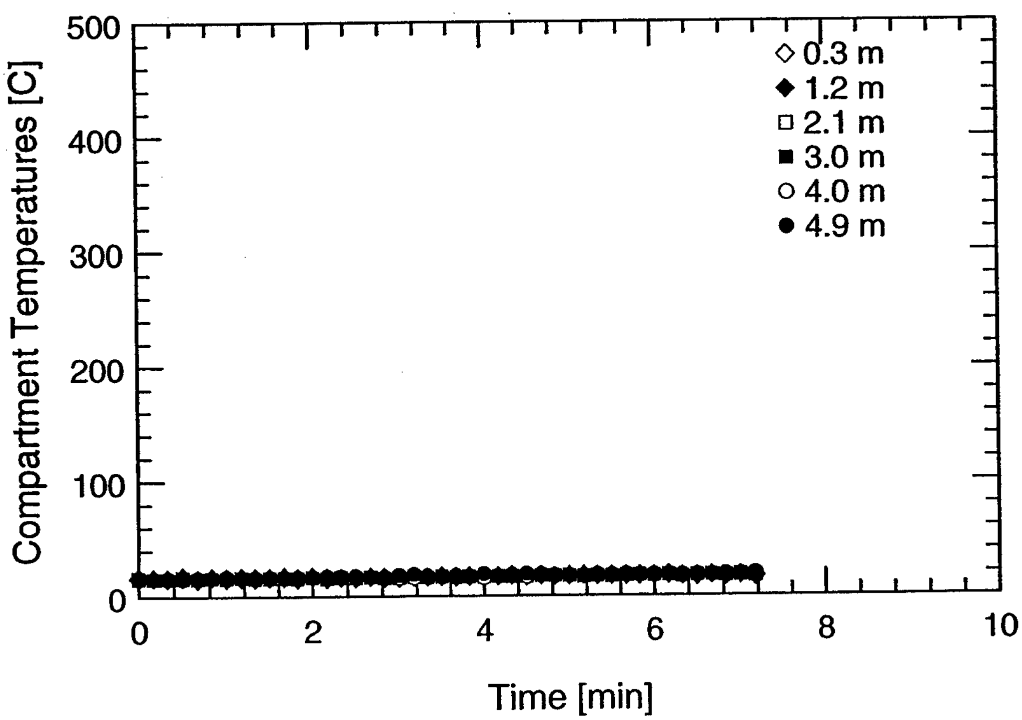


5-27-1

Test #53

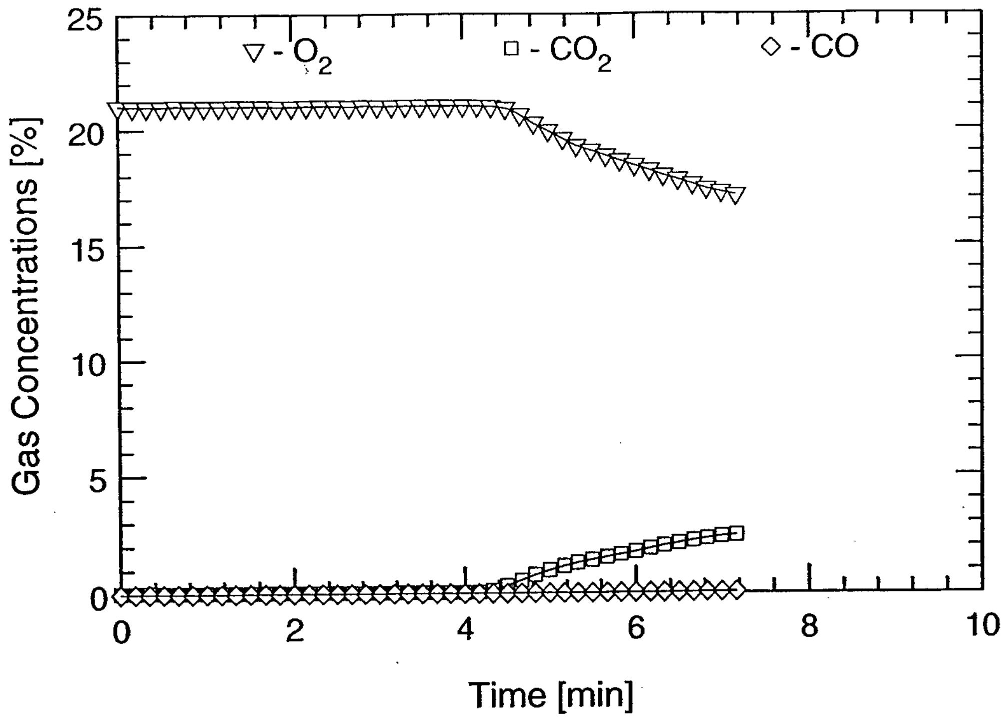


5-27-2

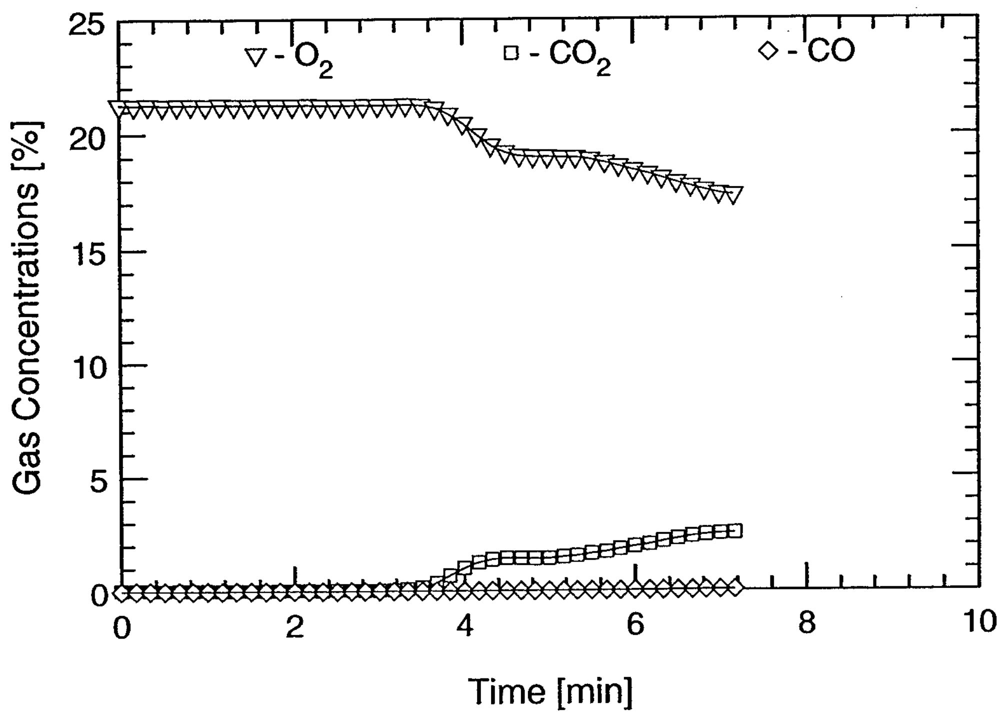


5-35-1

Test #53

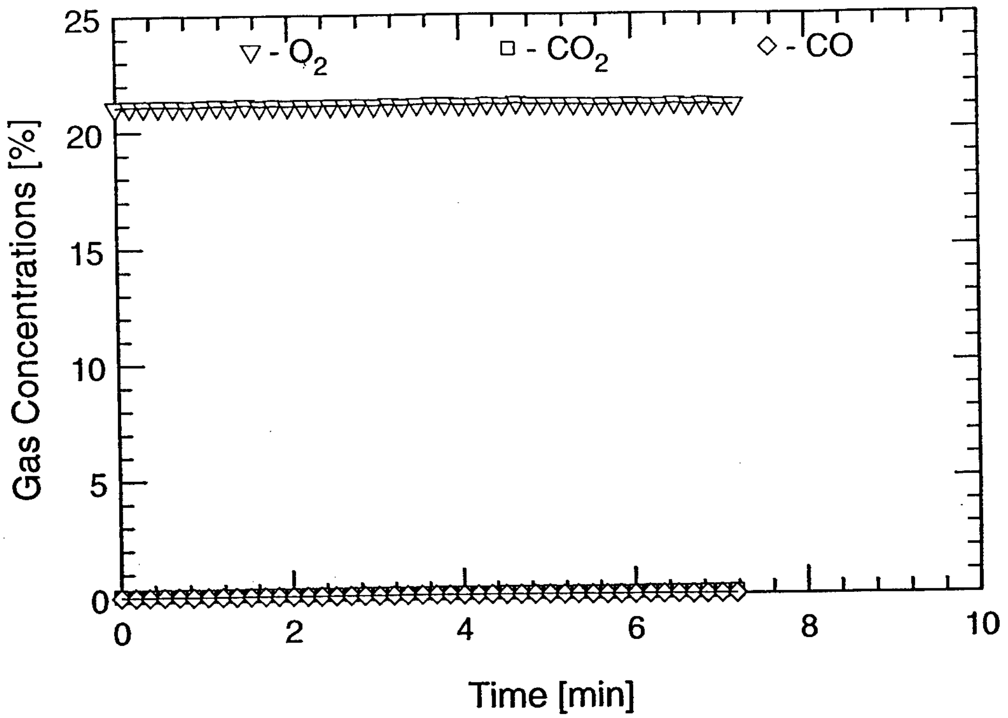


FR 22 - 0.5 m

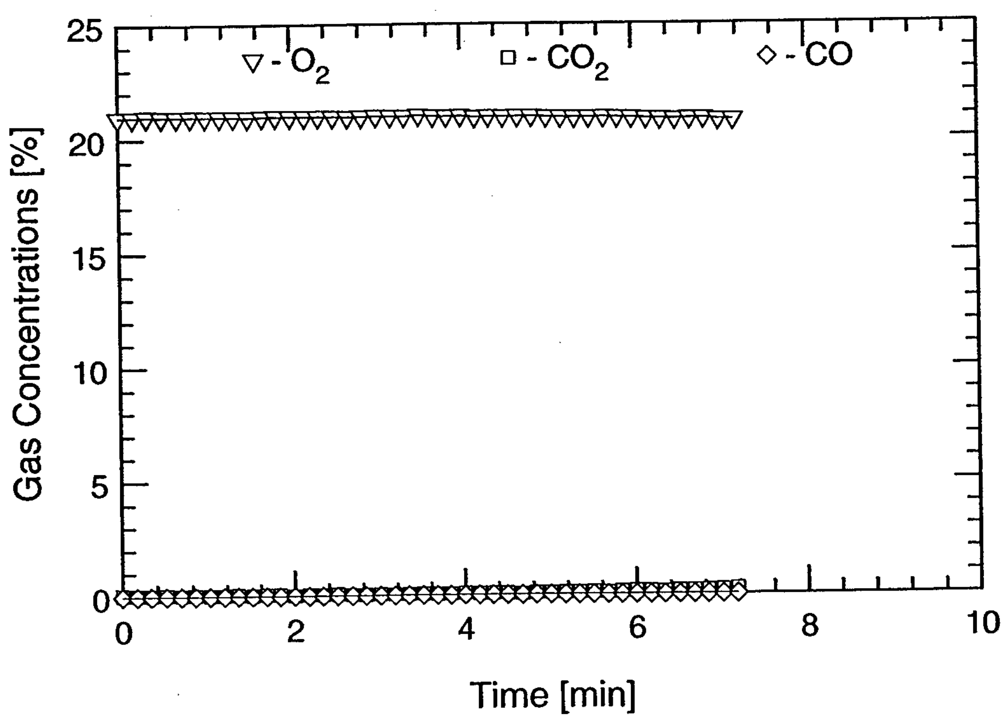


FR 22 - 4.5 m

Test #53

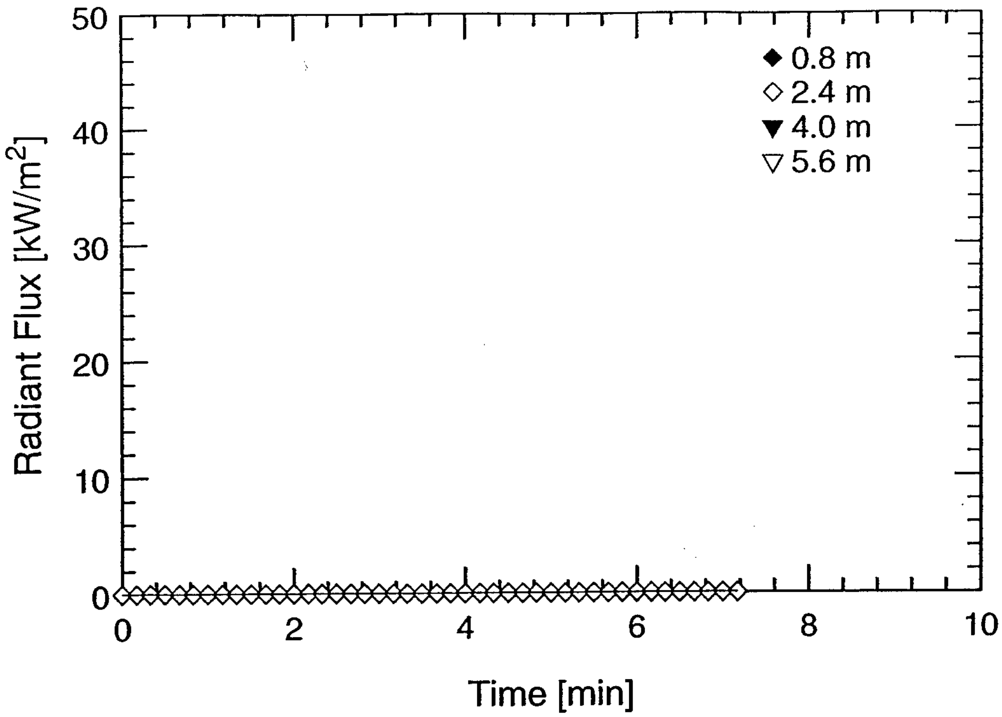


FR 36 - 0.5 m

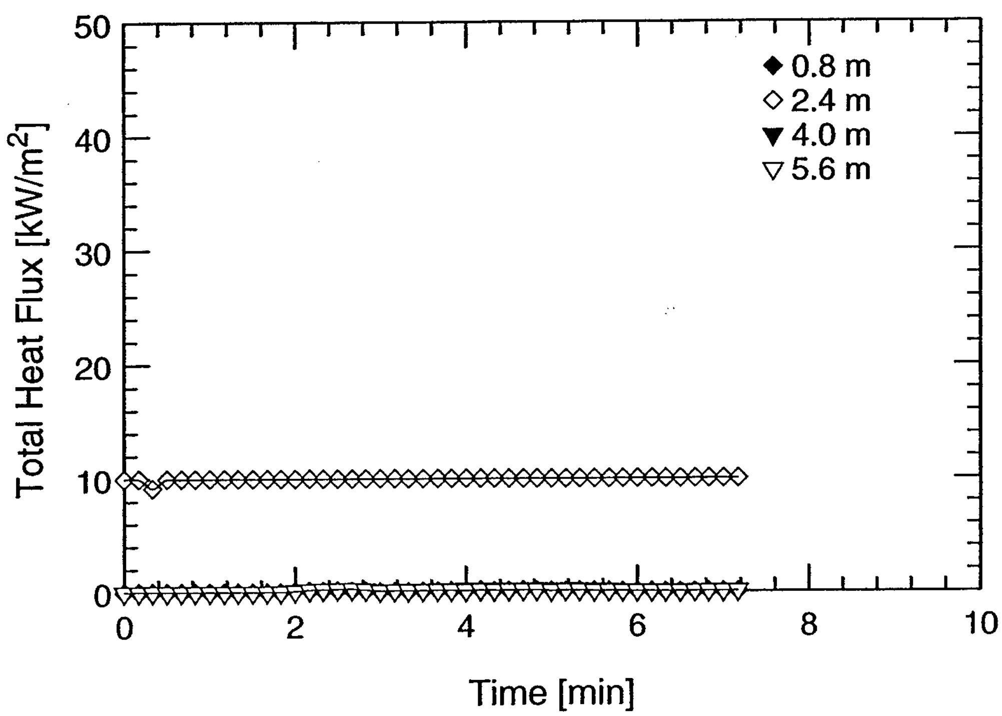


FR 36 - 4.5 m

Test #53

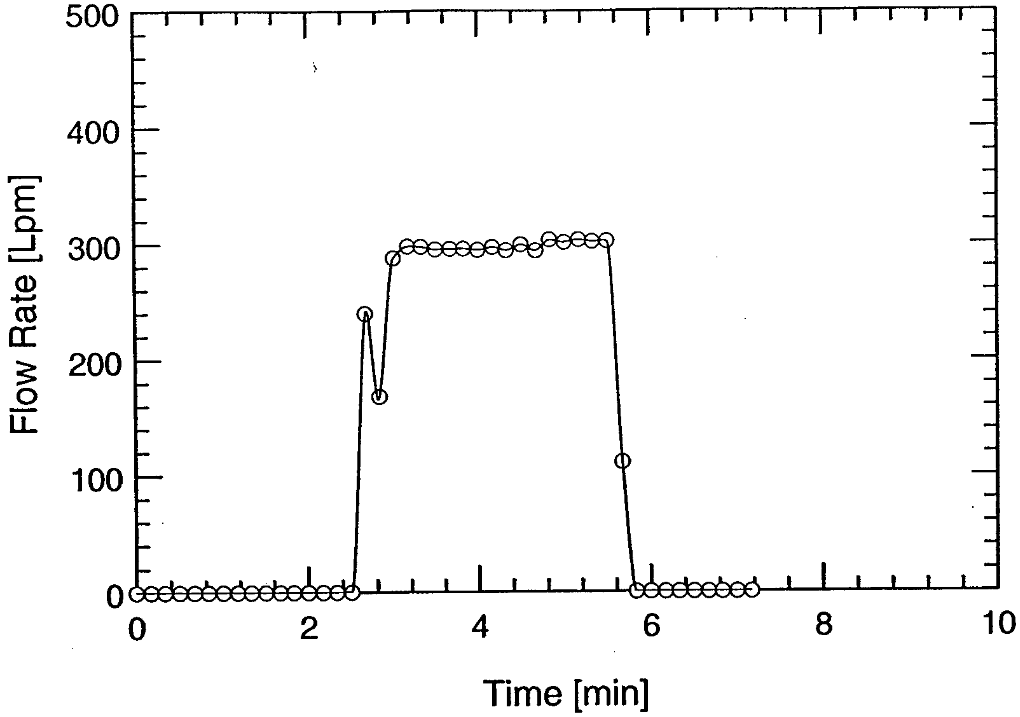


FR 22

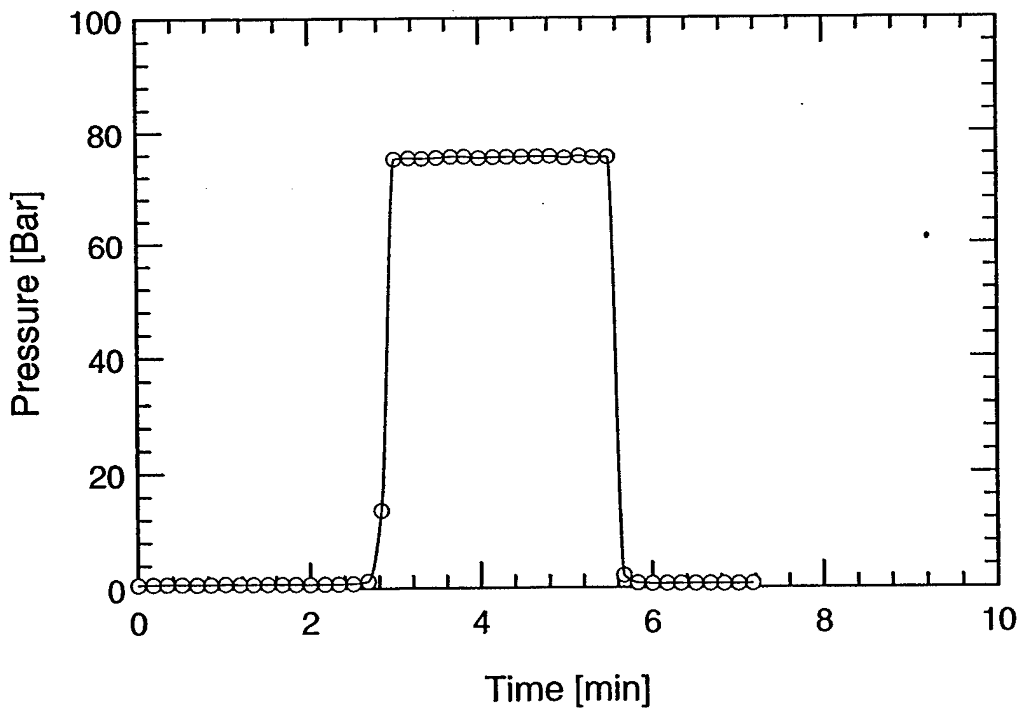


FR 22

Test #53

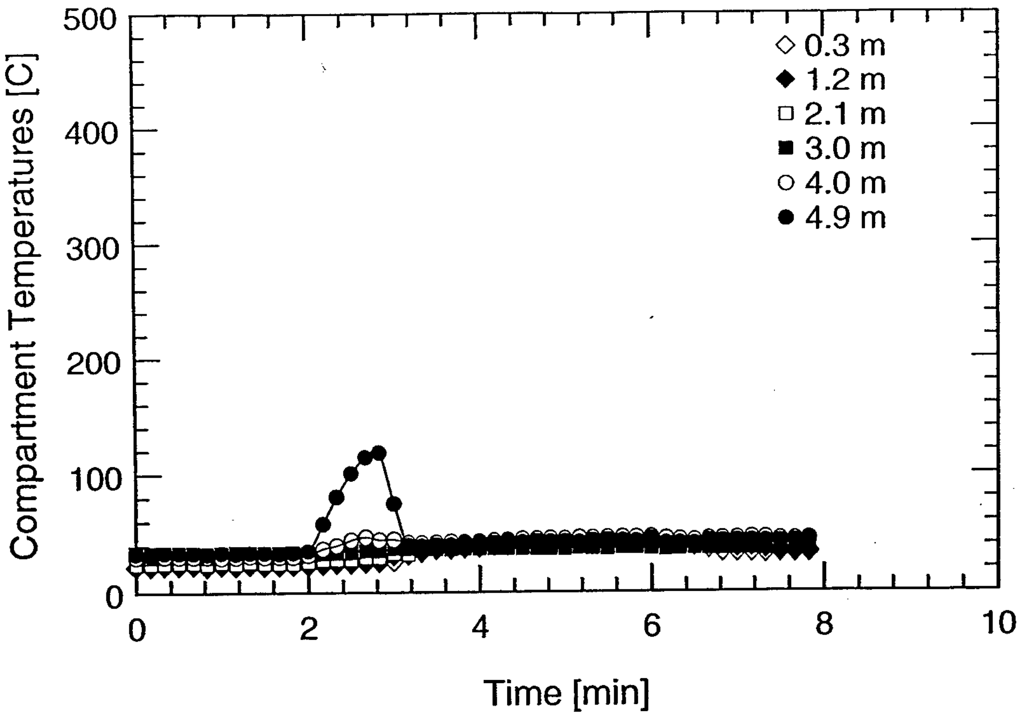


Water Mist System Flow Rate

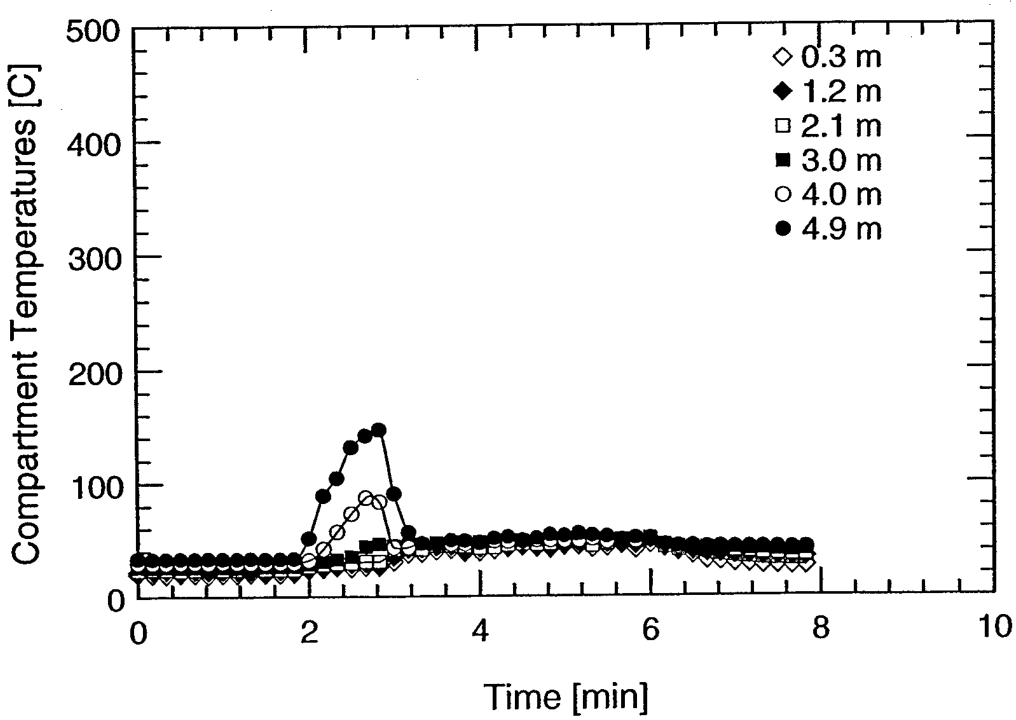


Water Mist System Pressure

Test #53

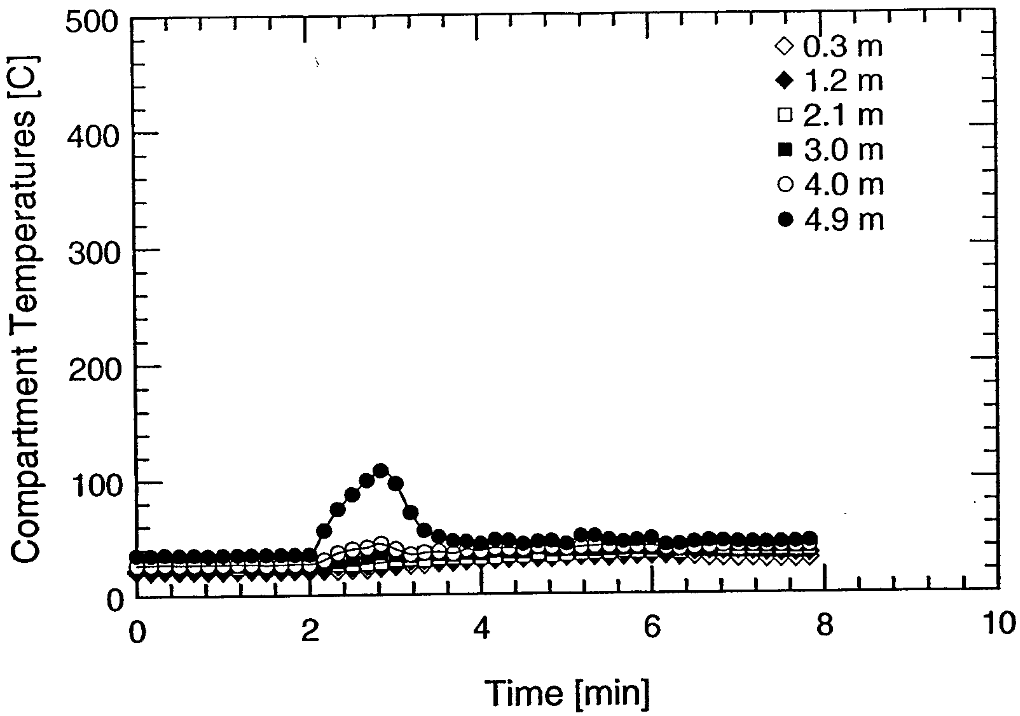


5-22-1

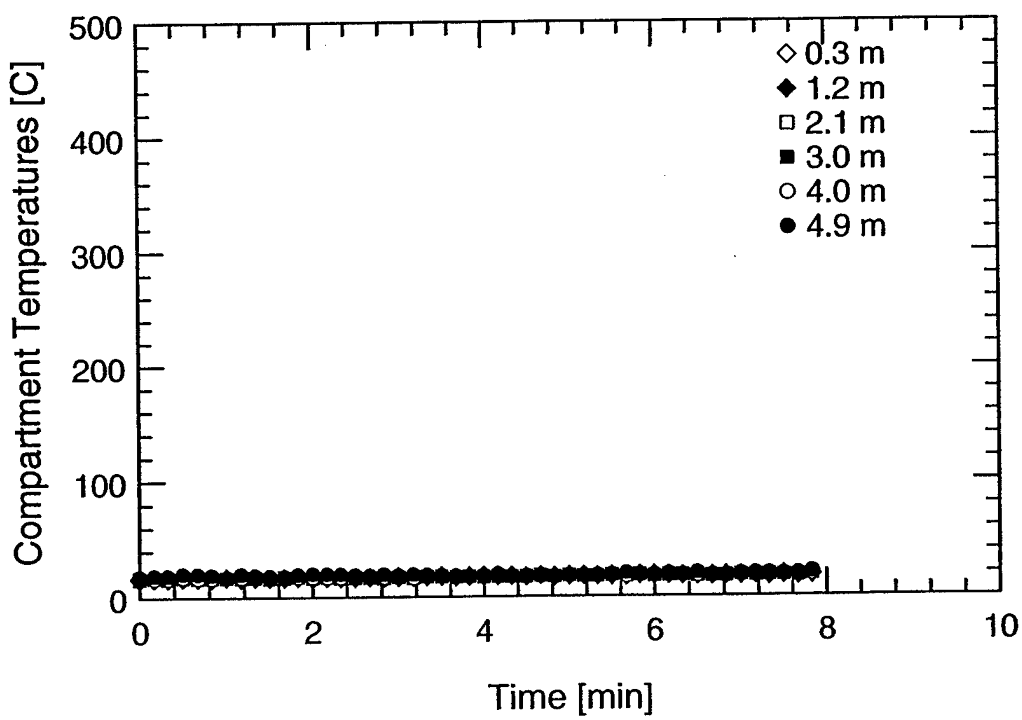


5-27-1

Test #54

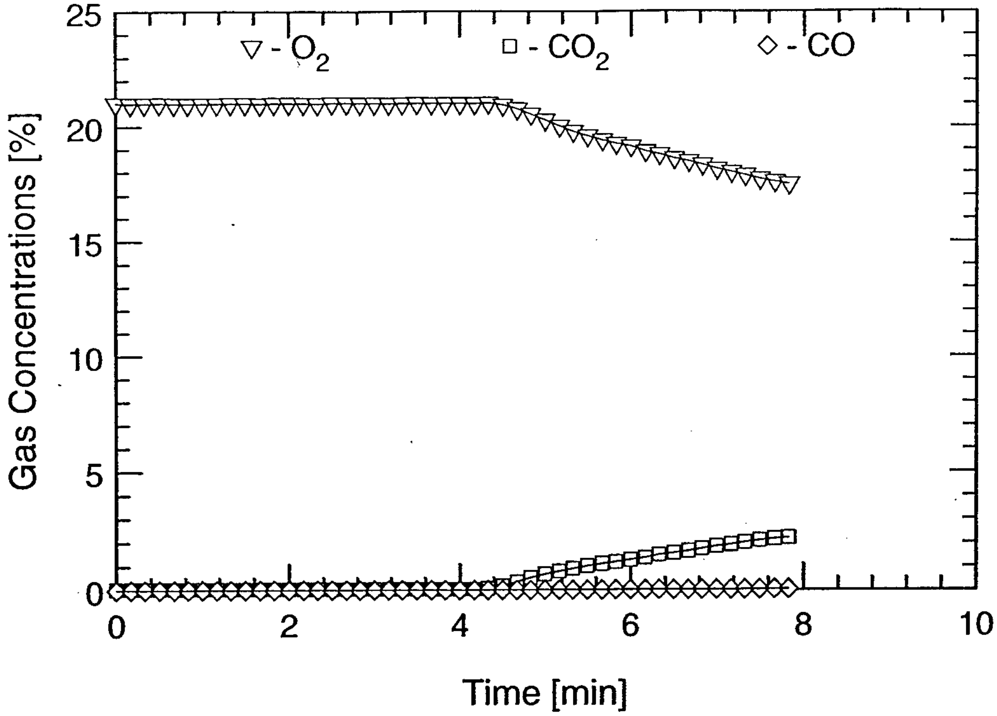


5-27-2

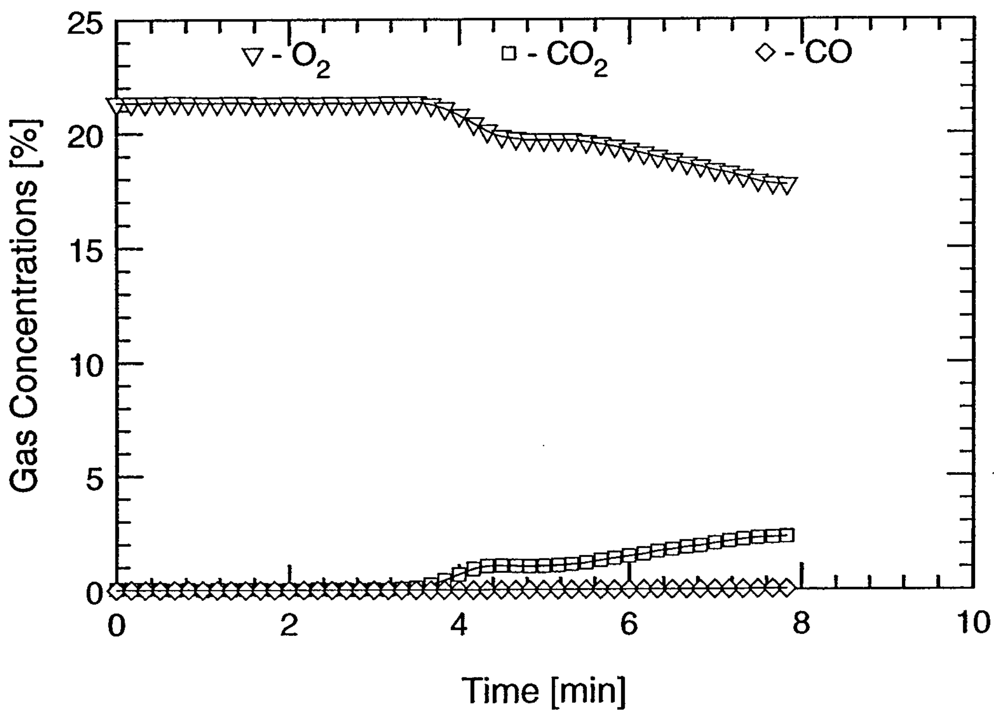


5-35-1

Test #54

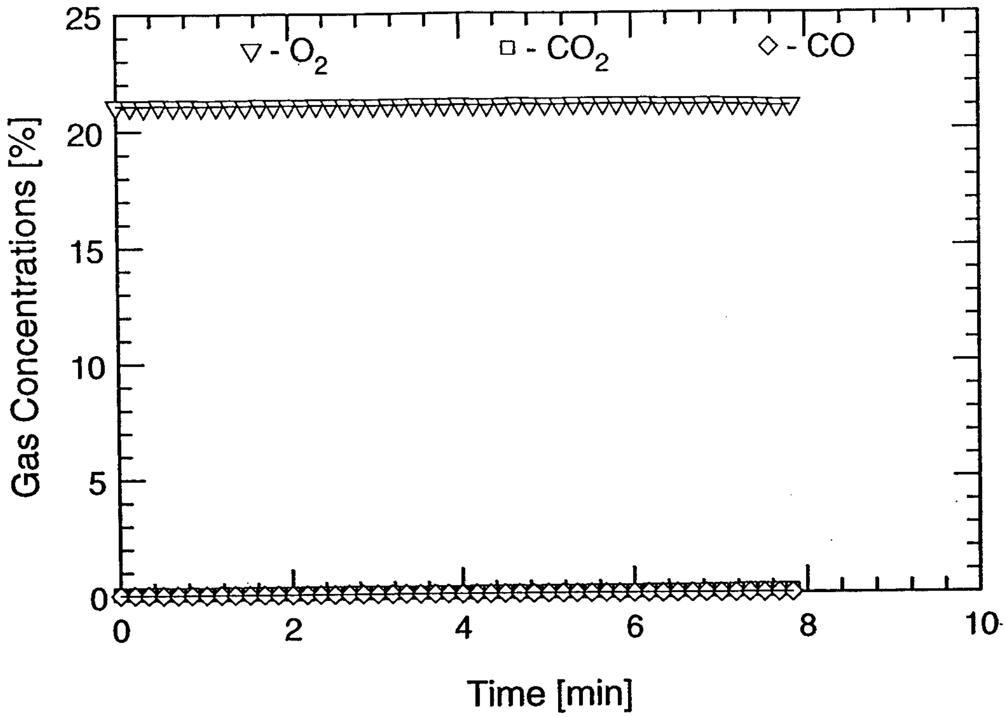


FR 22 - 0.5 m

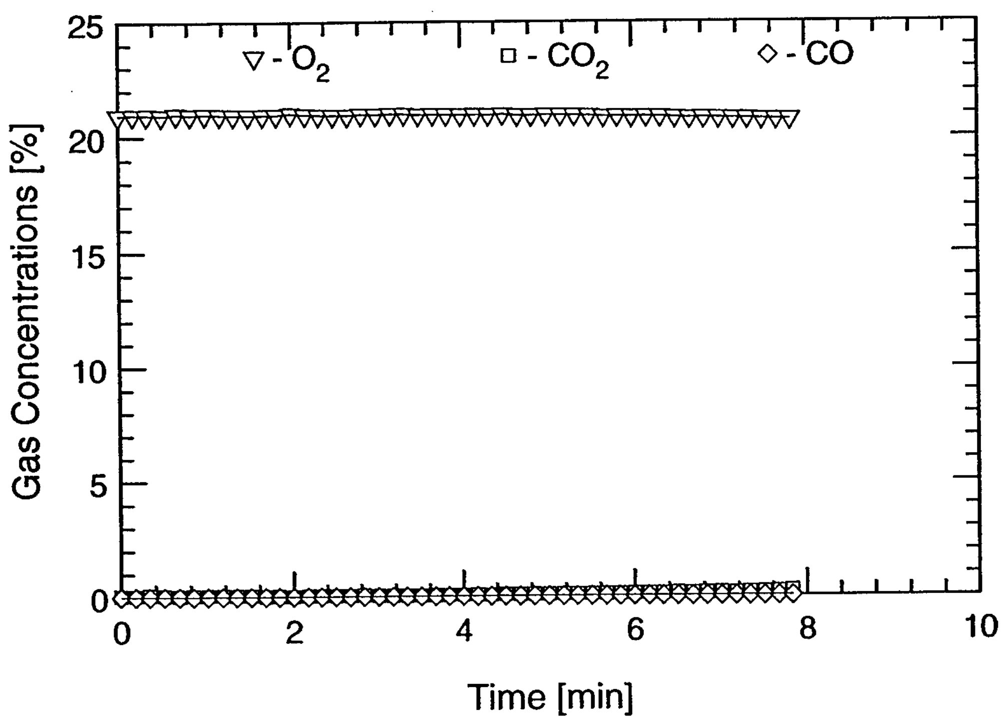


FR 22 - 4.5 m

Test #54

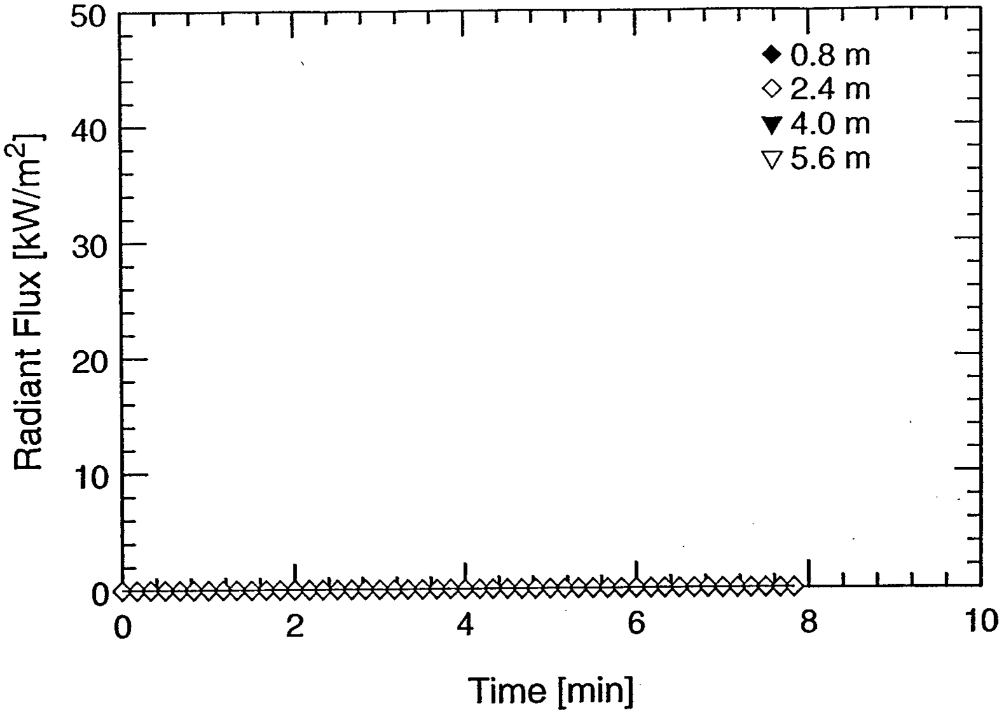


FR 36 - 0.5 m

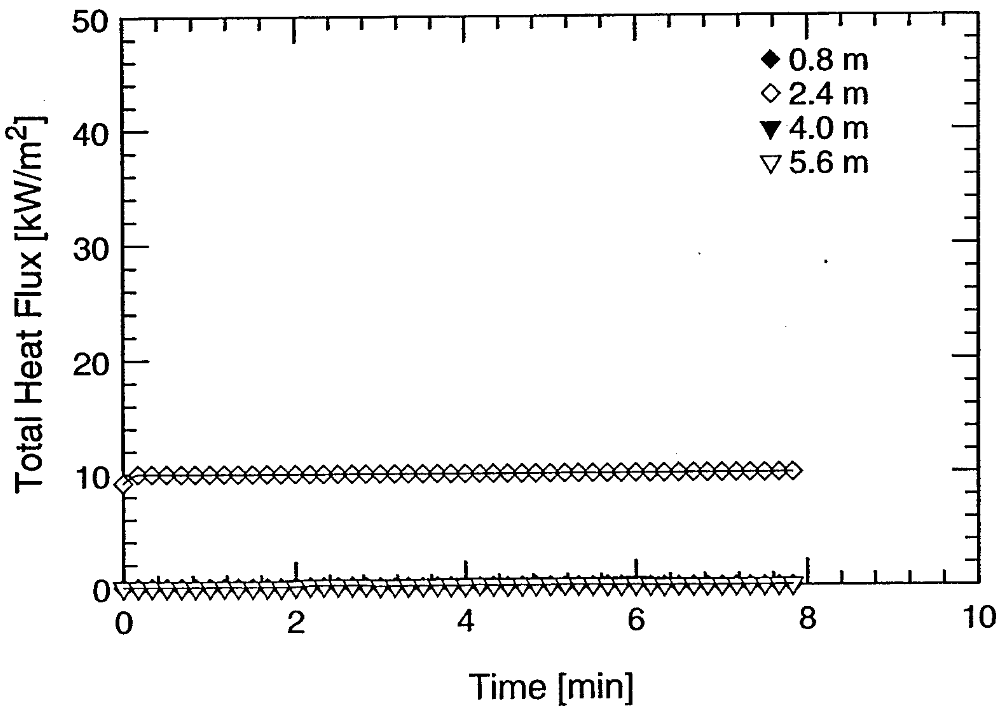


FR 36 - 4.5 m

Test #54

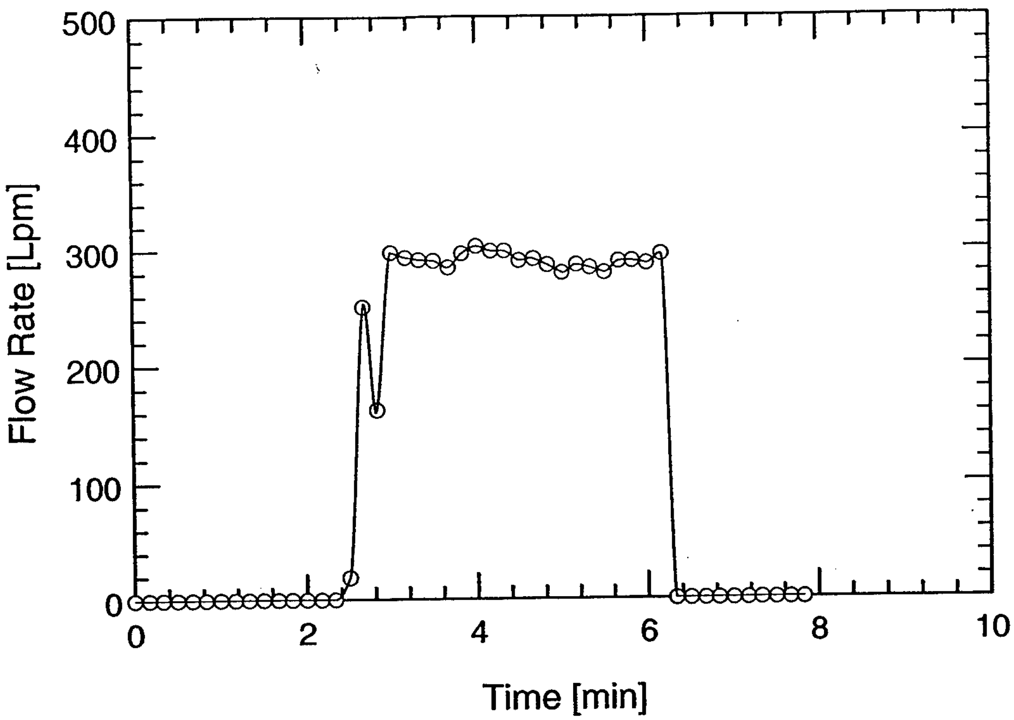


FR 22

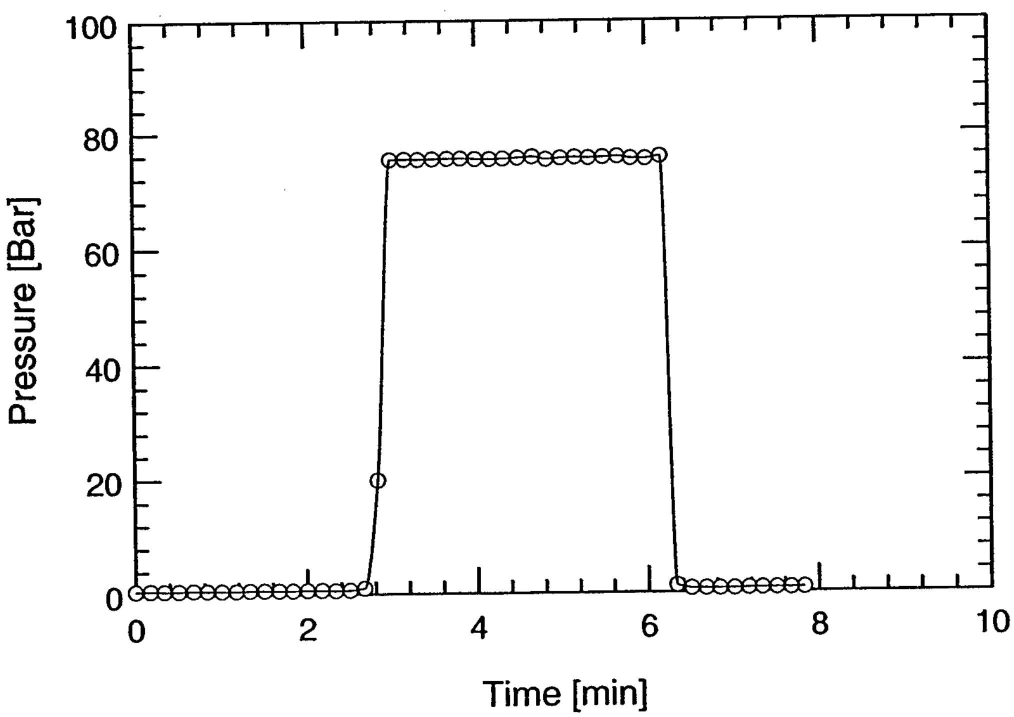


FR 22

Test #54

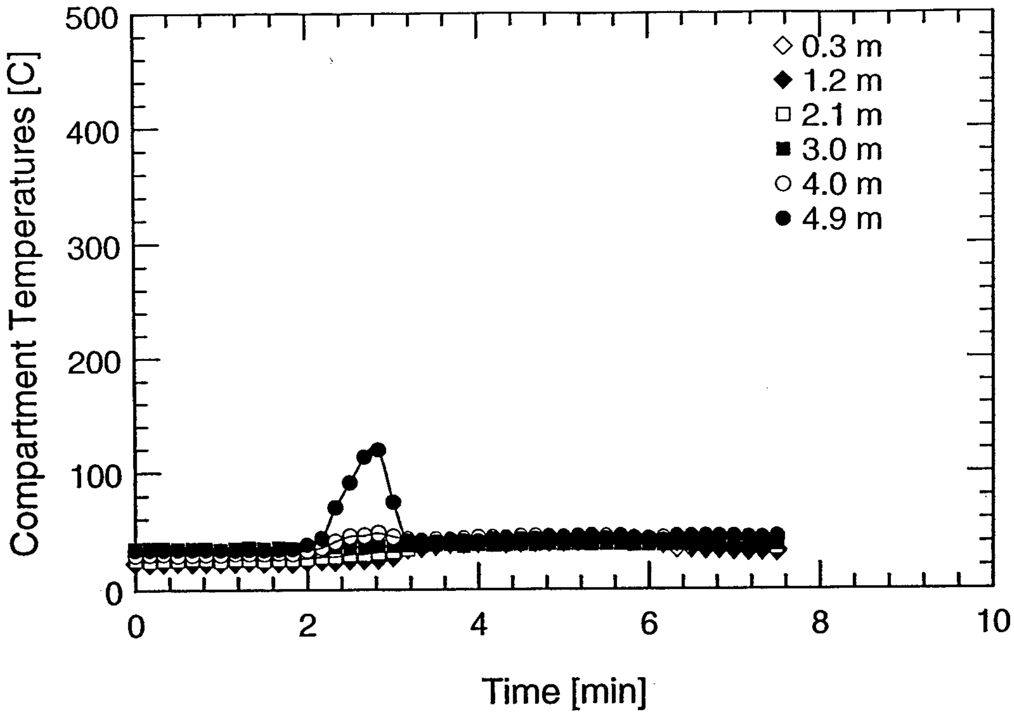


Water Mist System Flow Rate

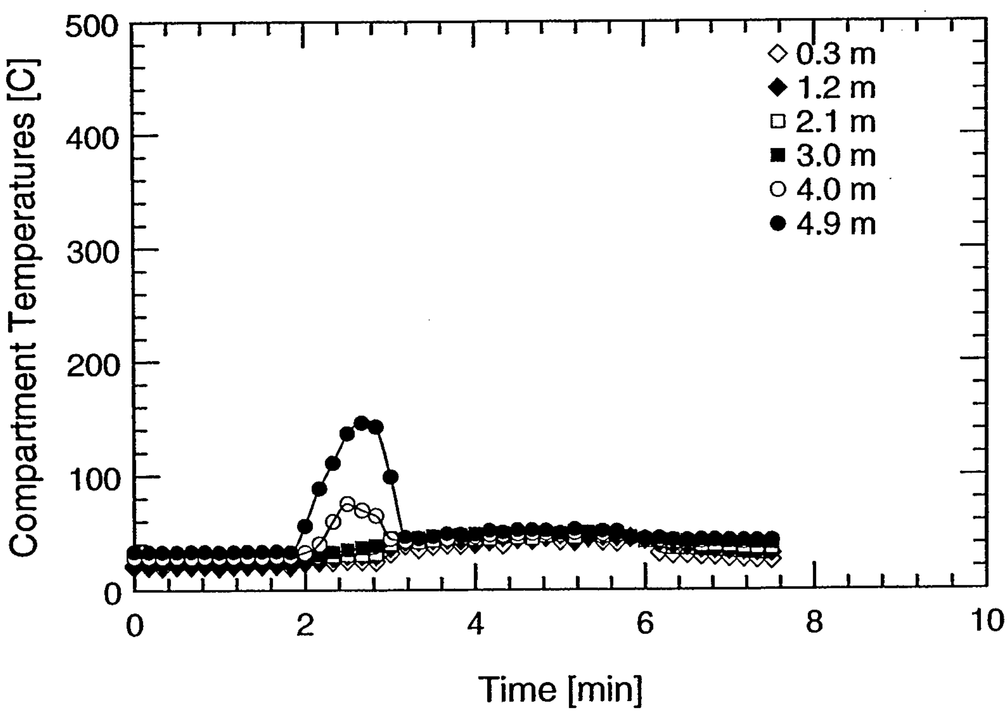


Water Mist System Pressure

Test #54

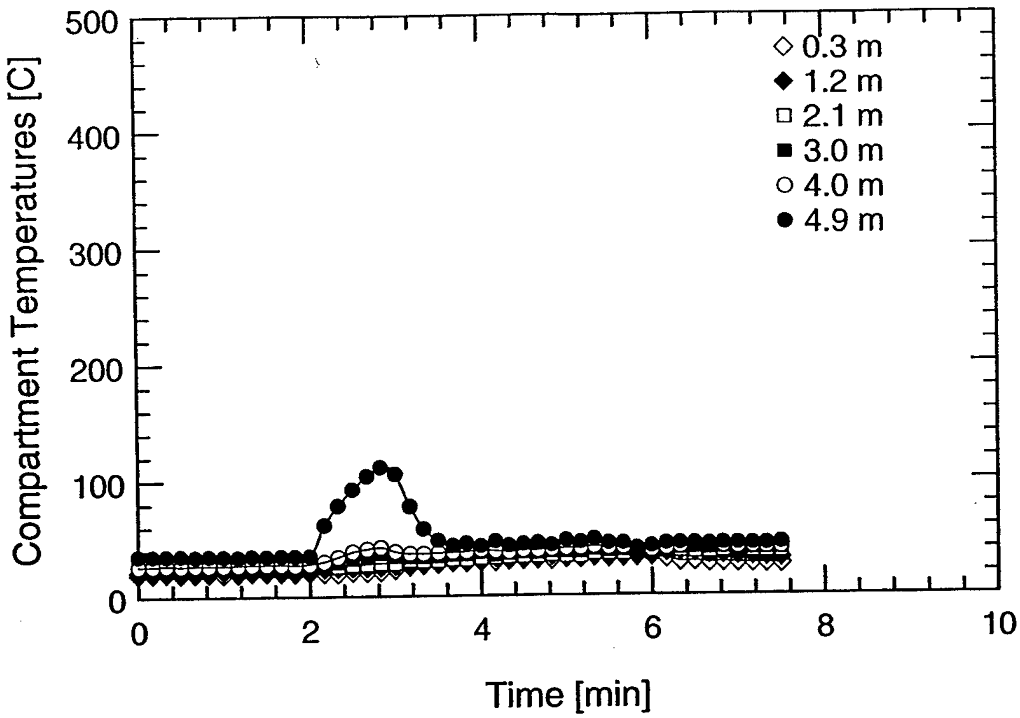


5-22-1

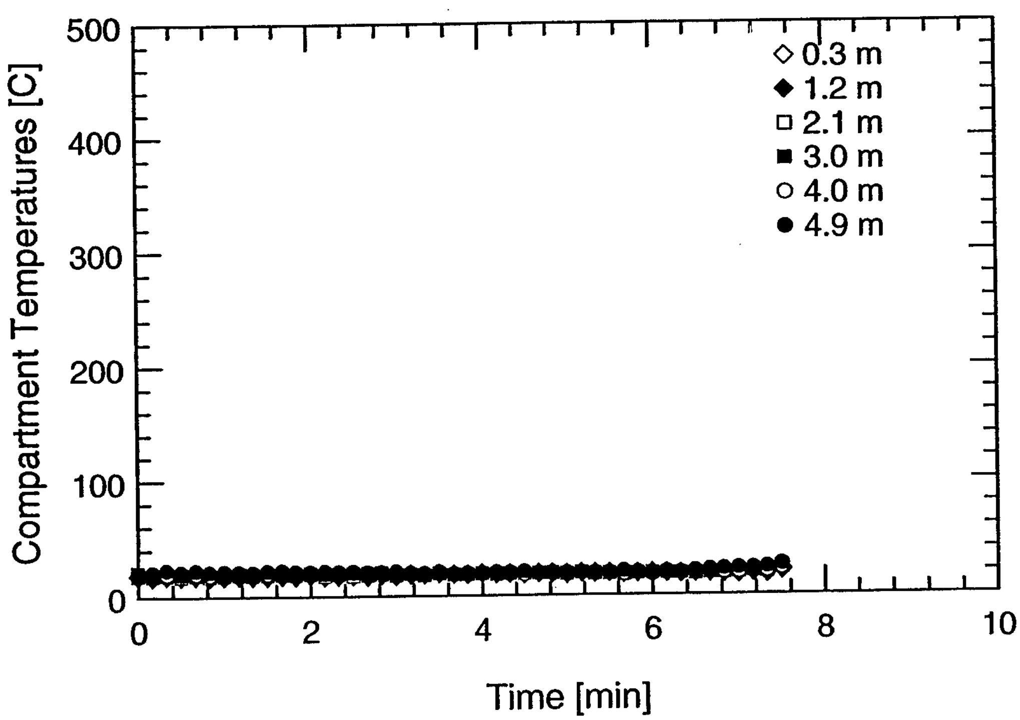


5-27-1

Test #55

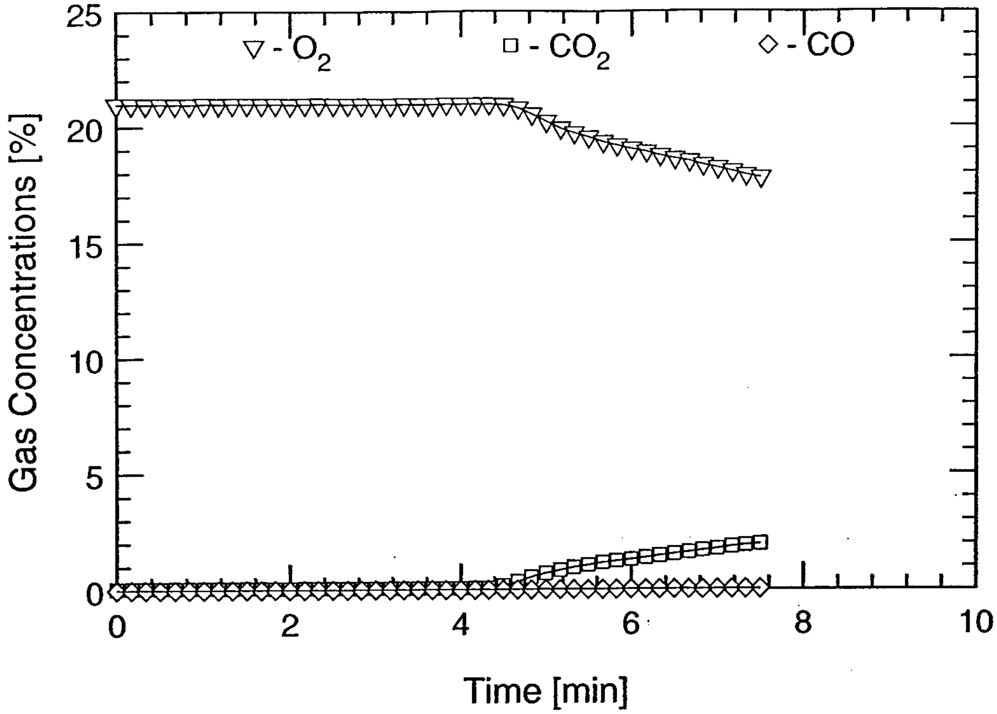


5-27-2

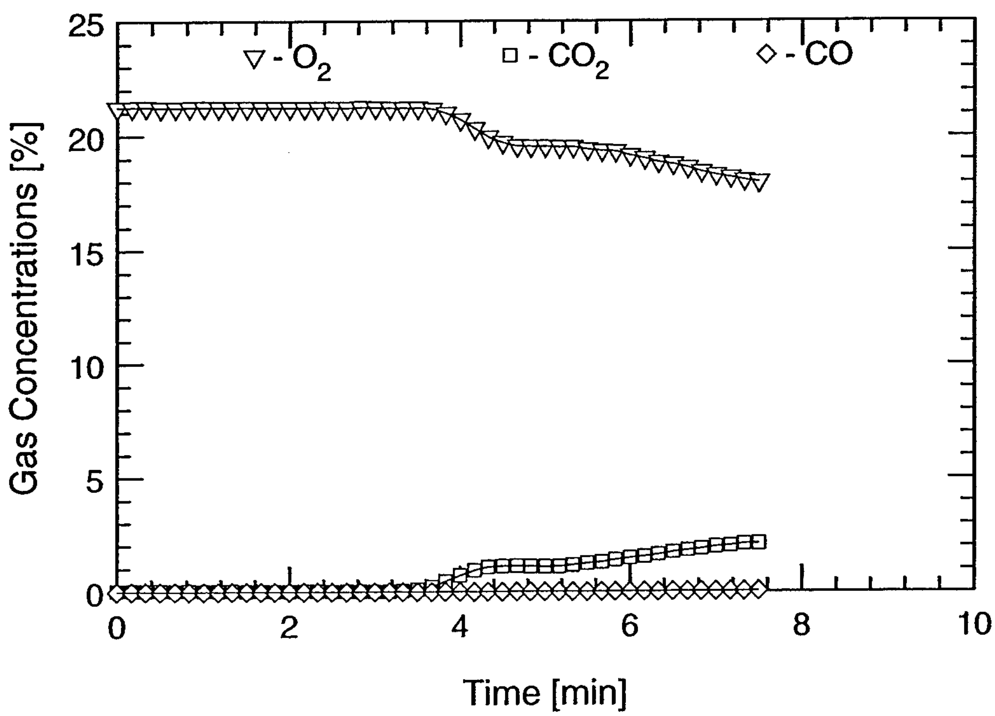


5-35-1

Test #55

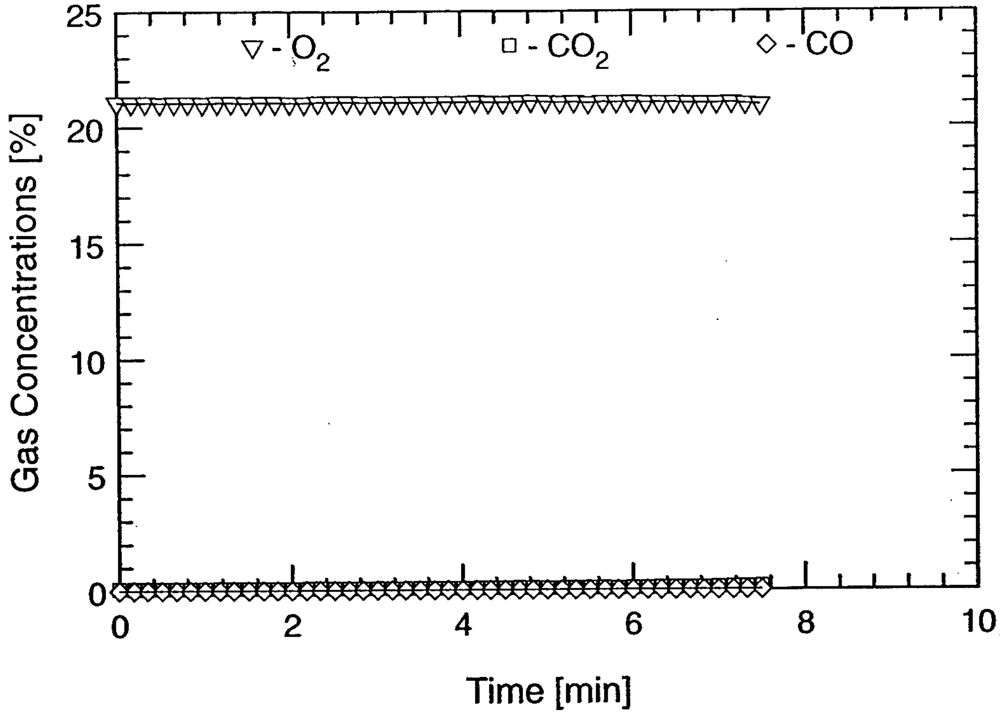


FR 22 - 0.5 m

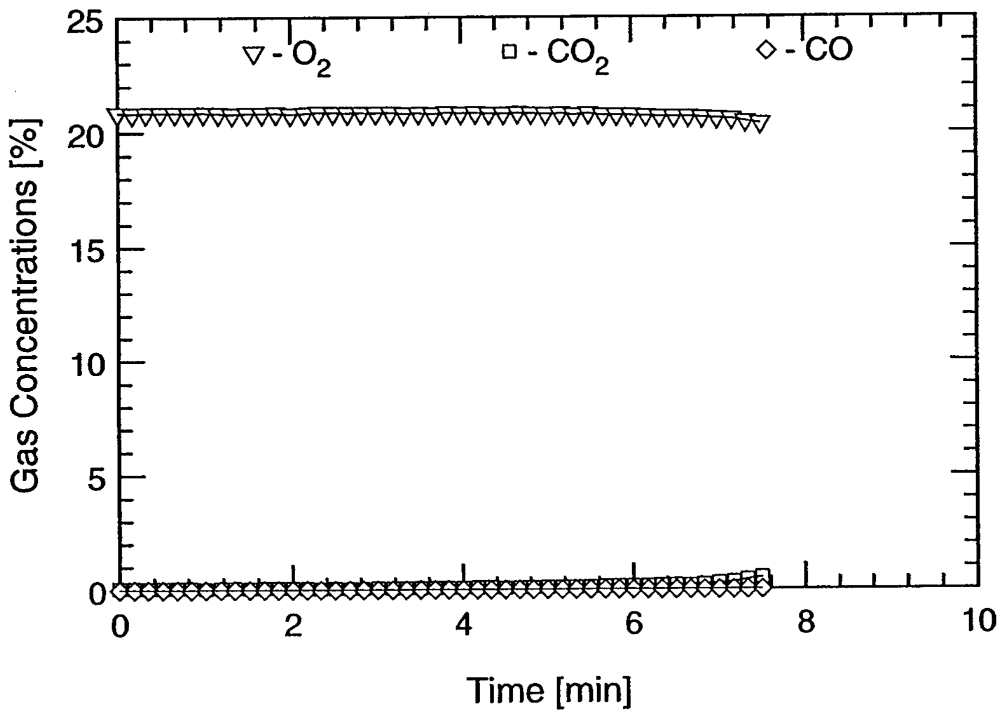


FR 22 - 4.5 m

Test #55

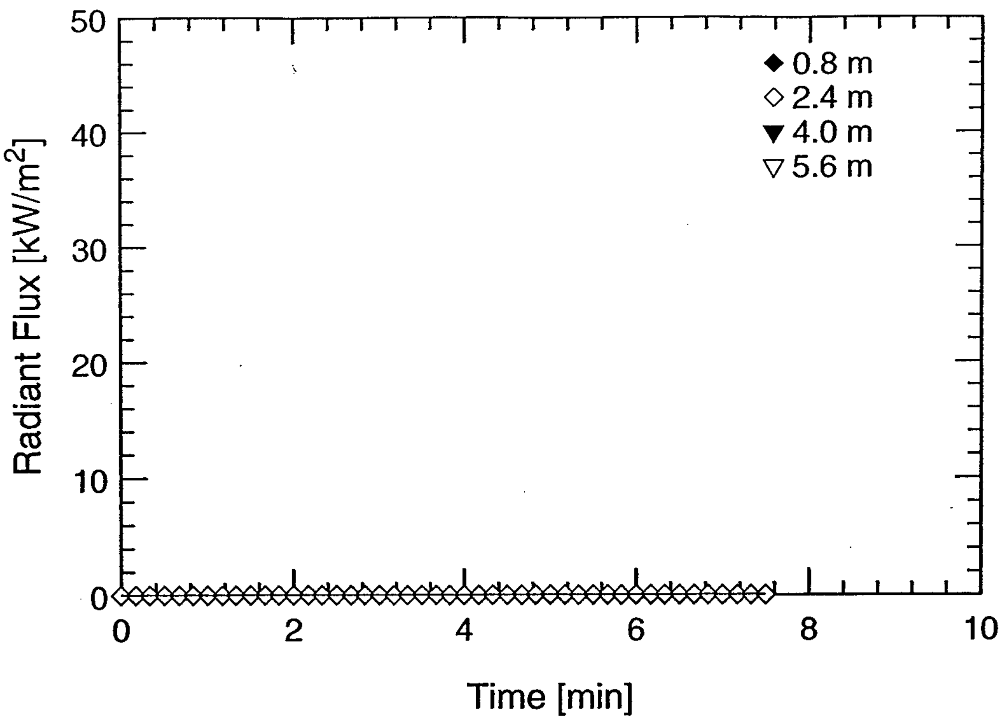


FR 36 - 0.5 m

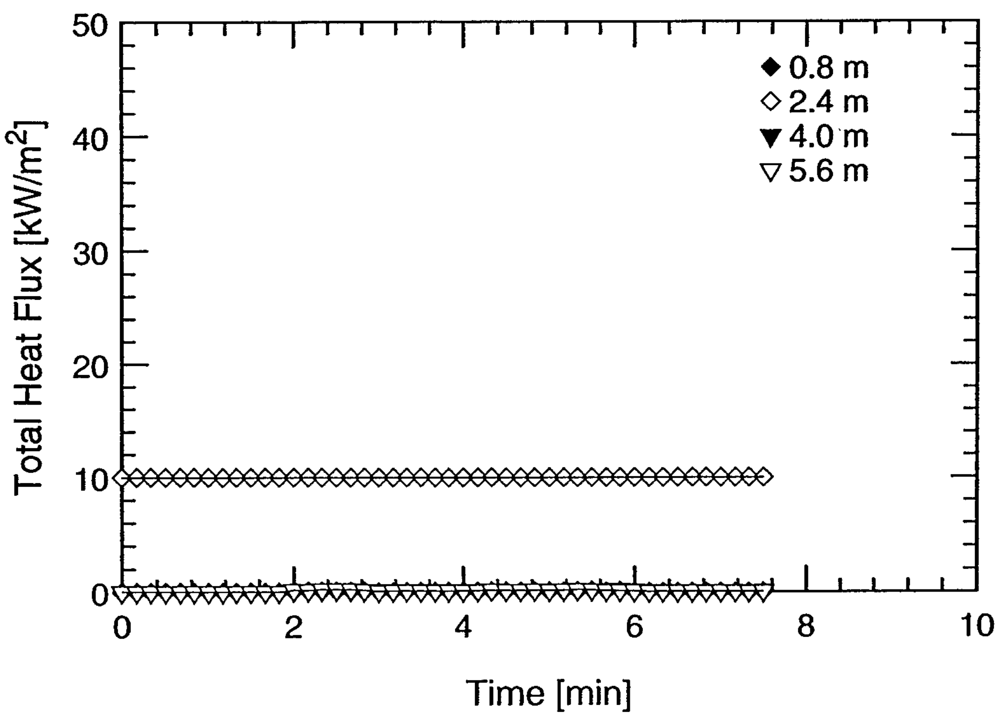


FR 36 - 4.5 m

Test #55

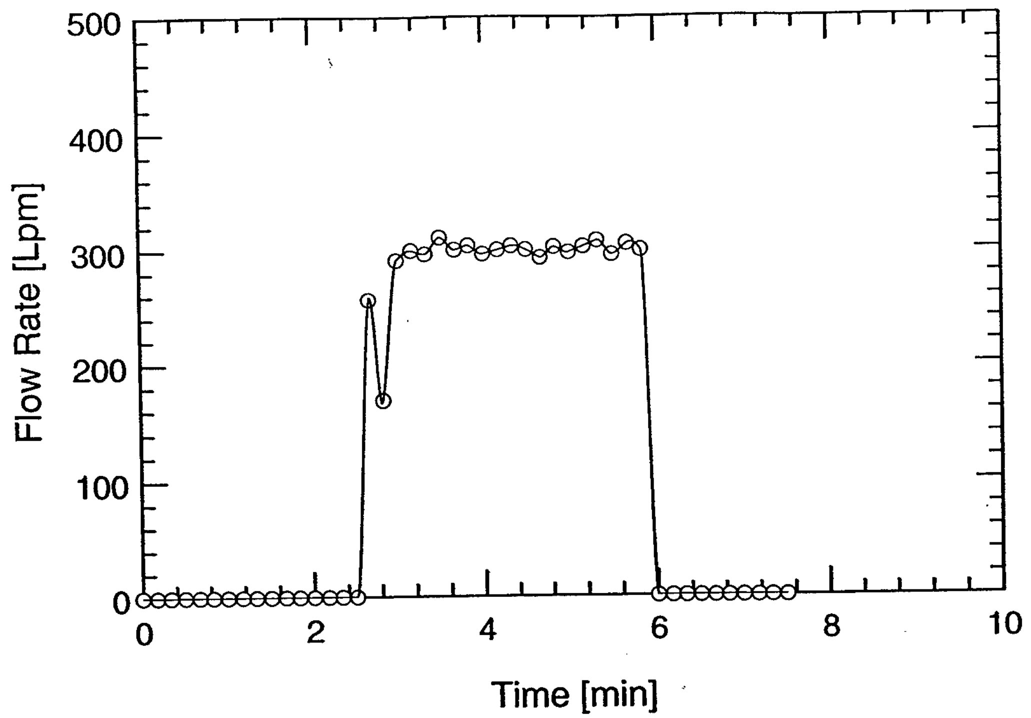


FR 22

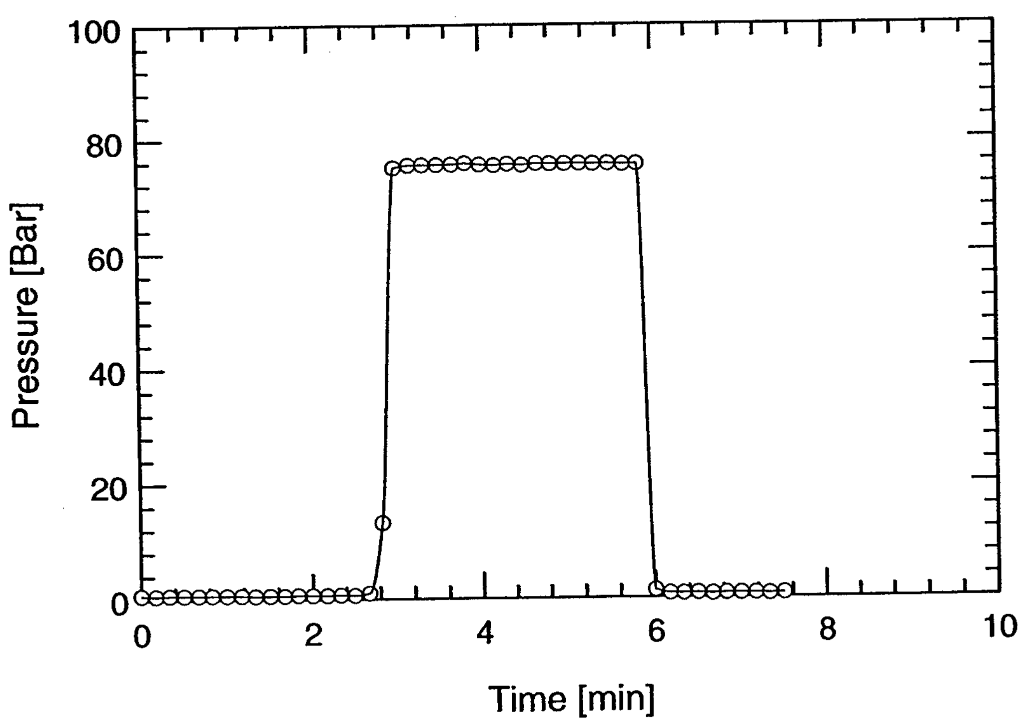


FR 22

Test #55

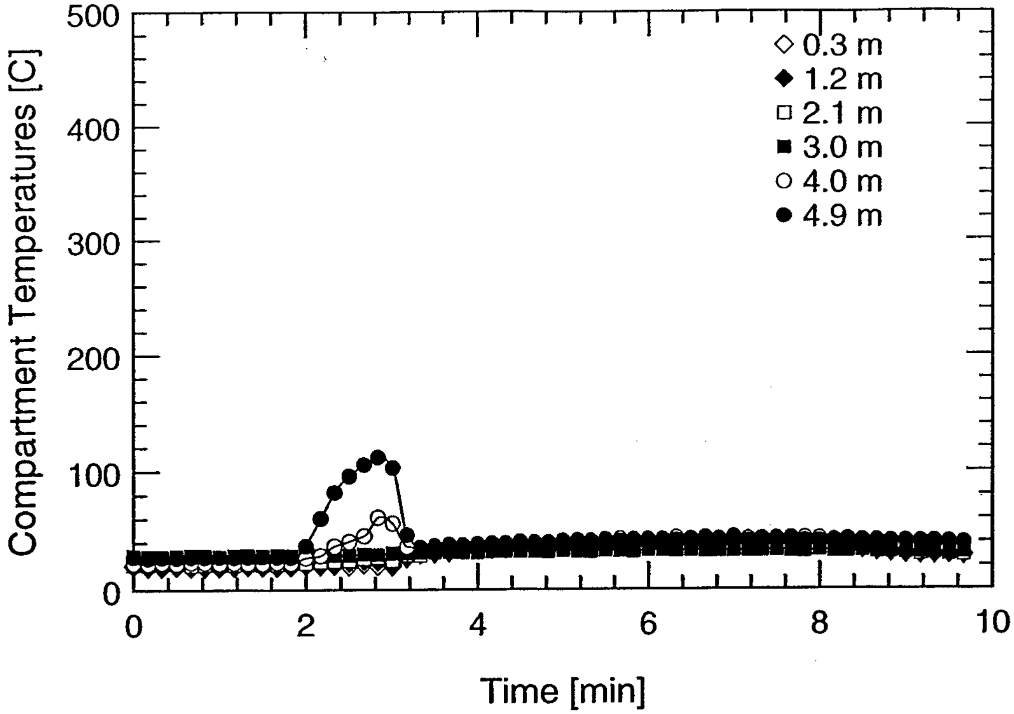


Water Mist System Flow Rate

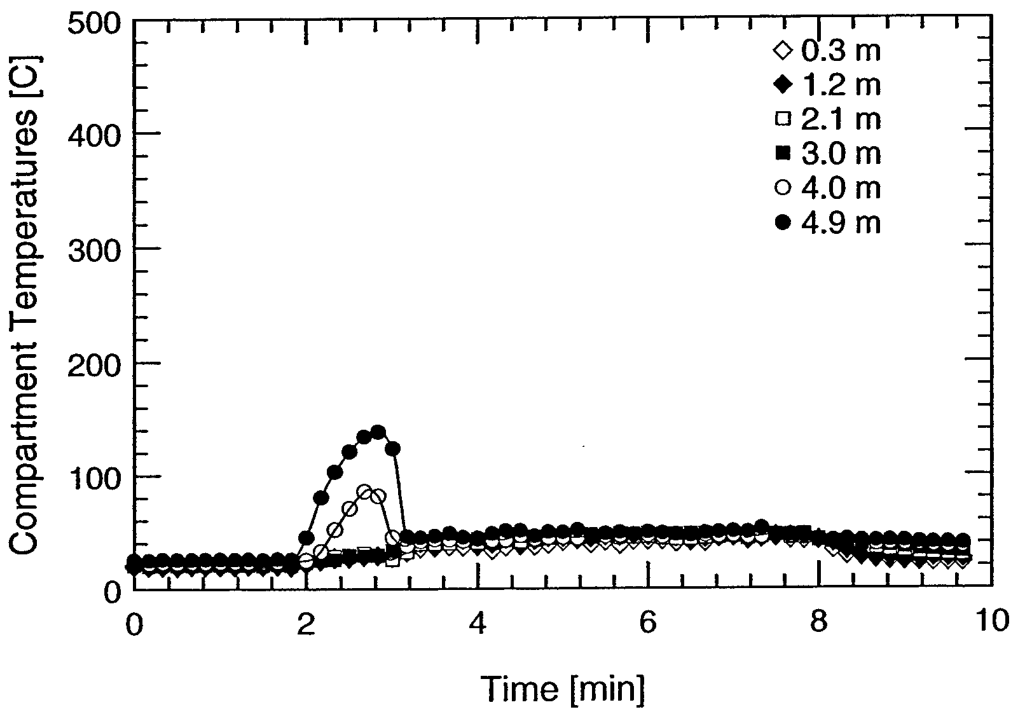


Water Mist System Pressure

Test #55

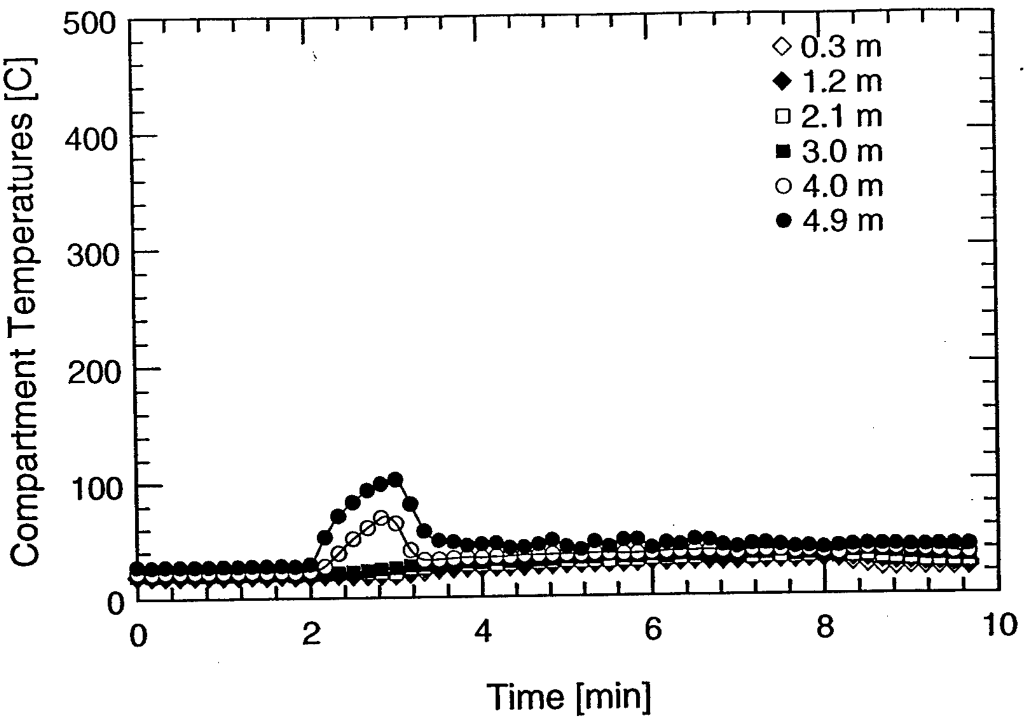


5-22-1

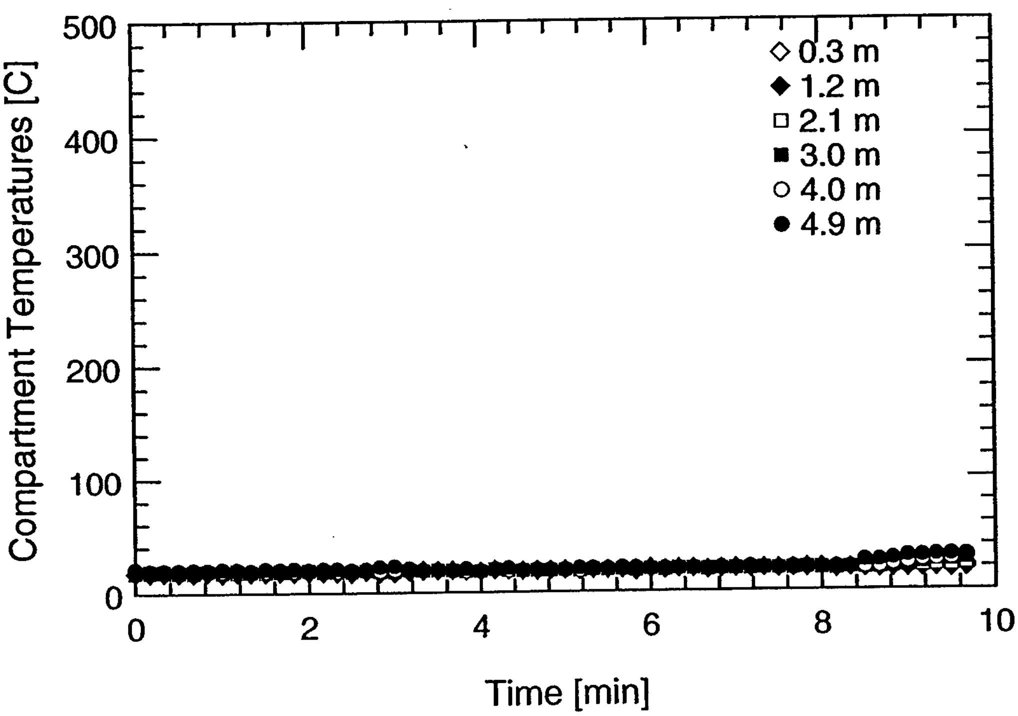


5-27-1

Test #56

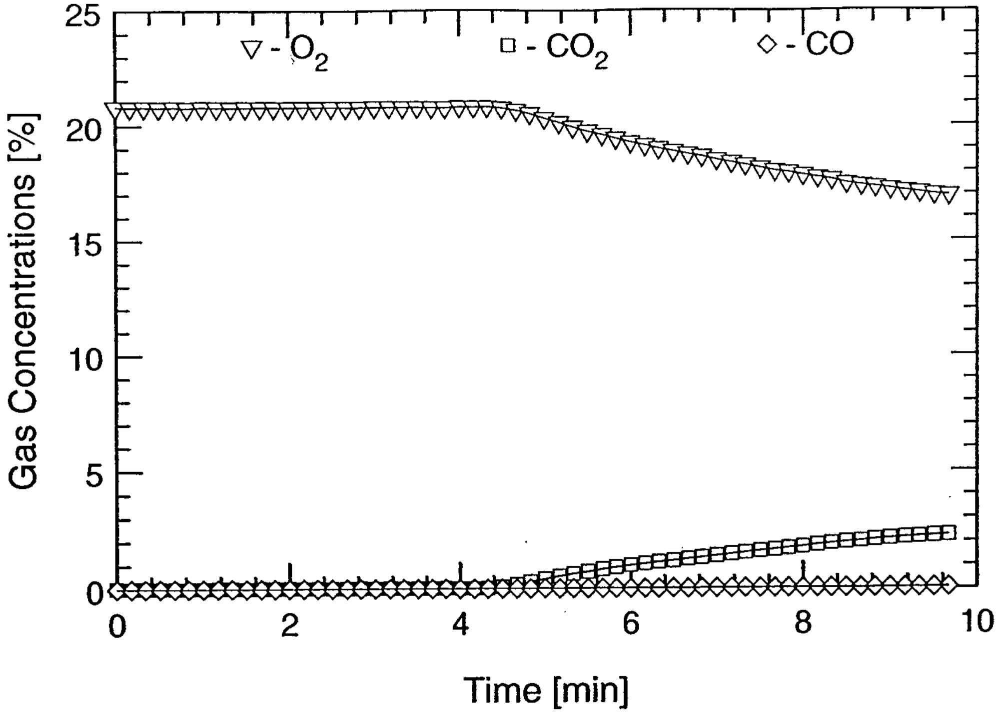


5-27-2

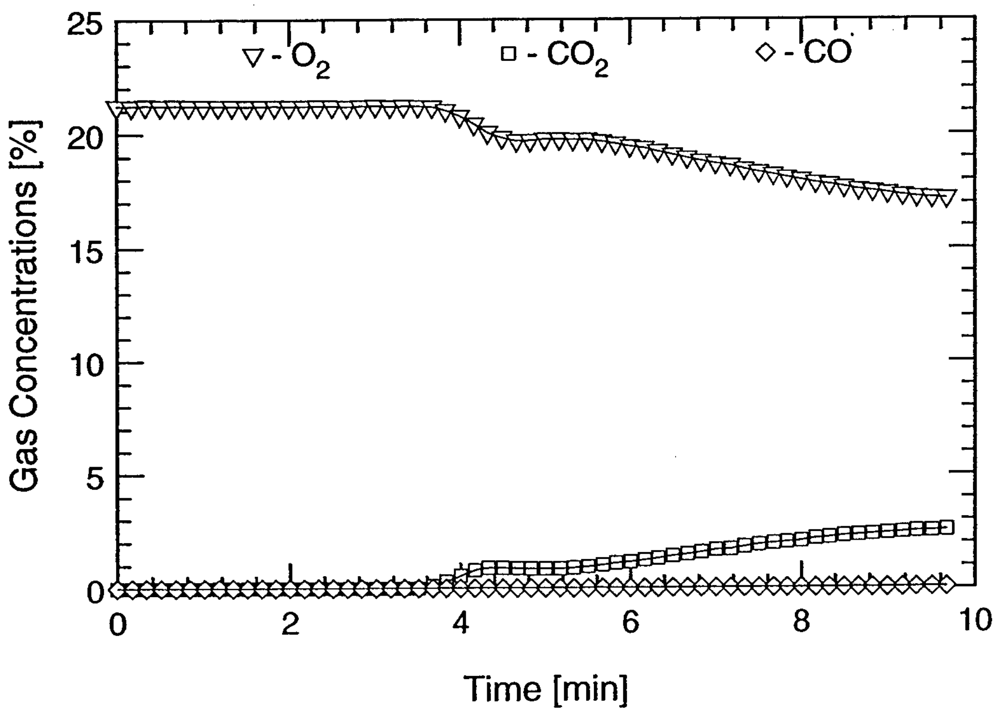


5-35-1

Test #56

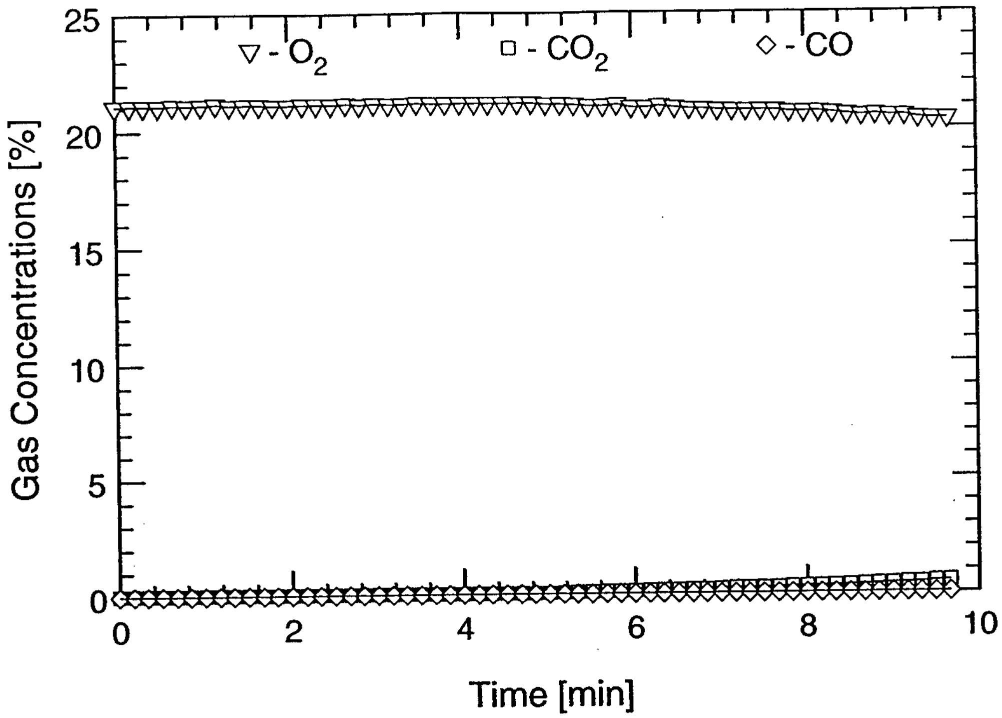


FR 22 - 0.5 m

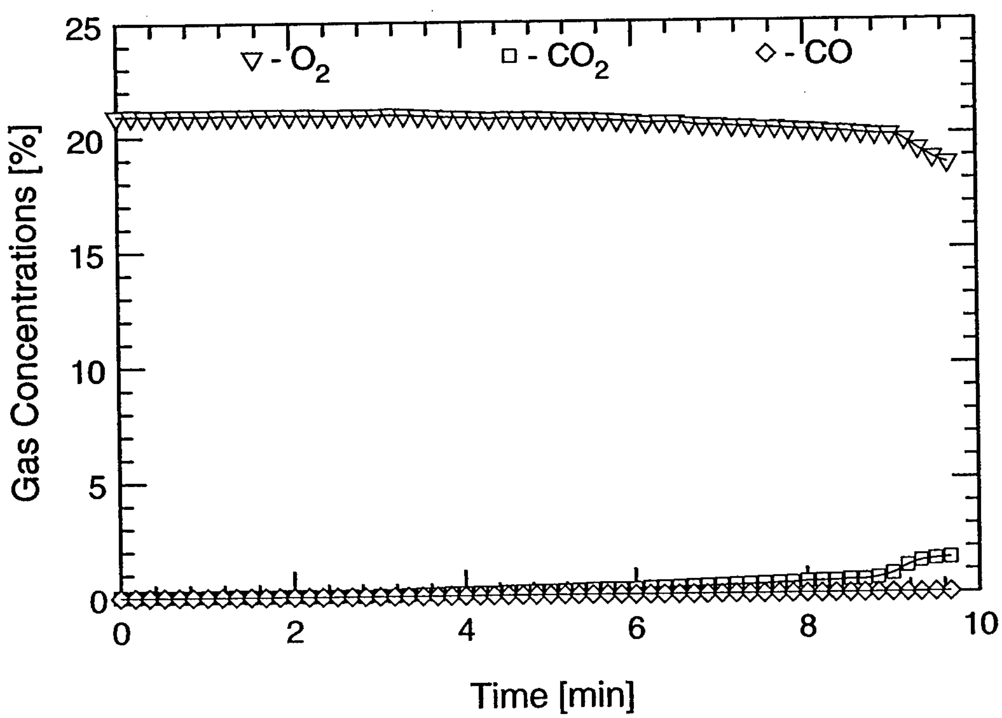


FR 22 - 4.5 m

Test #56

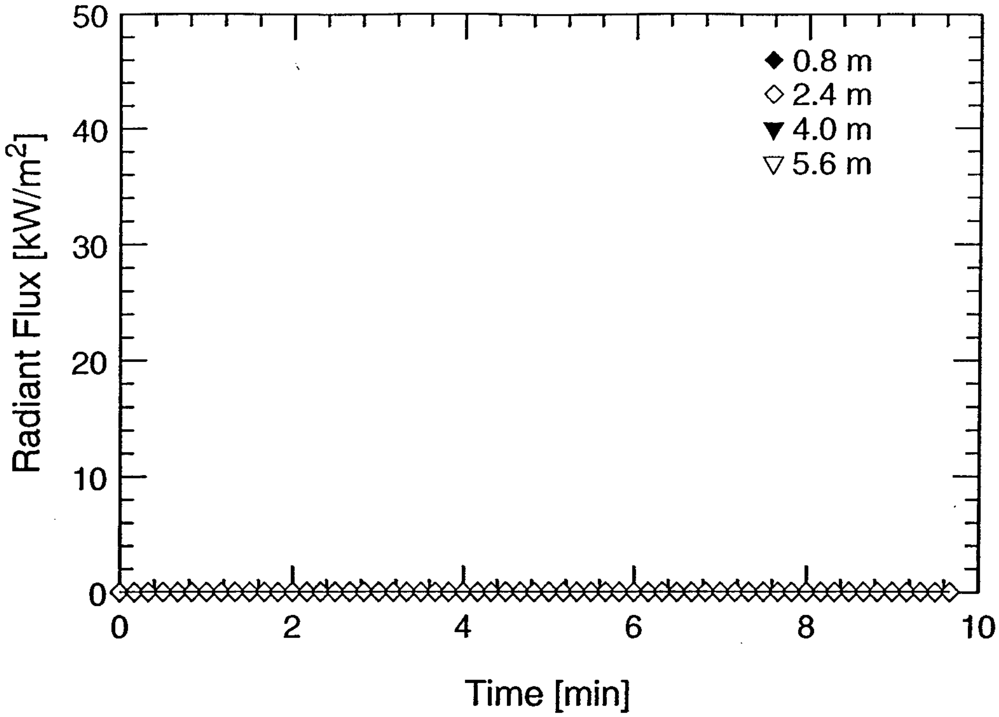


FR 36 - 0.5 m

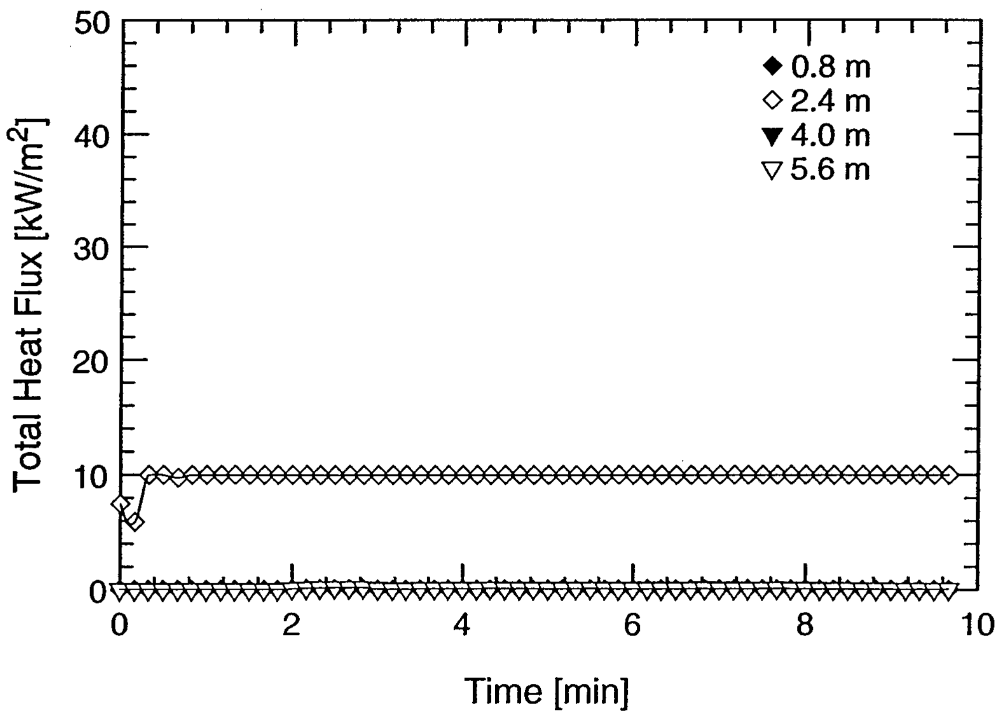


FR 36 - 4.5 m

Test #56

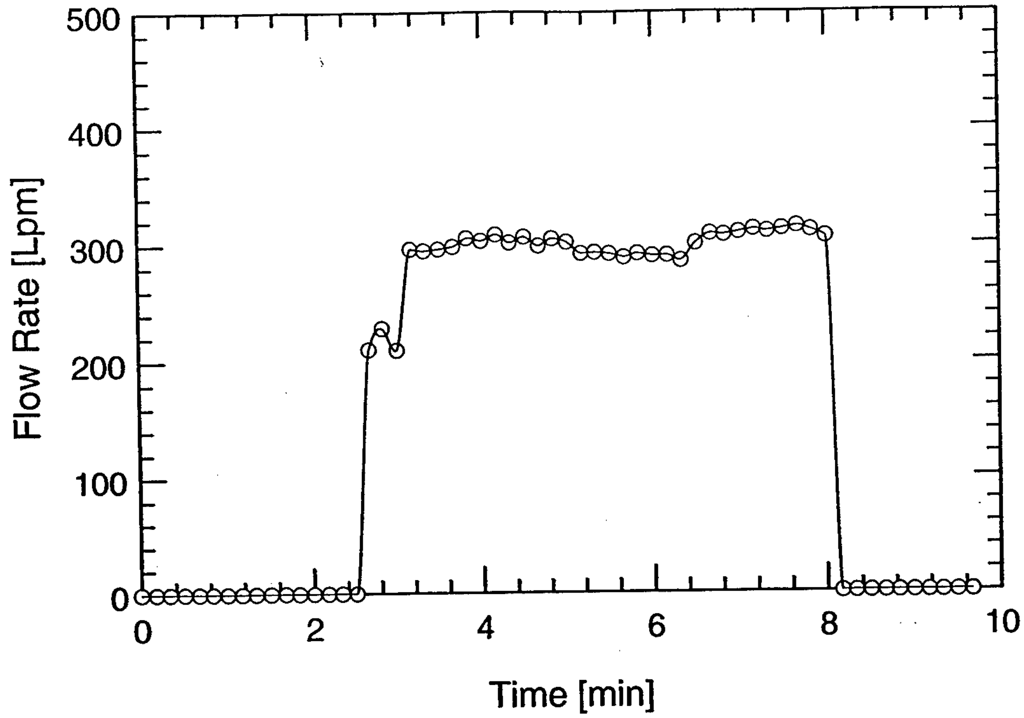


FR 22

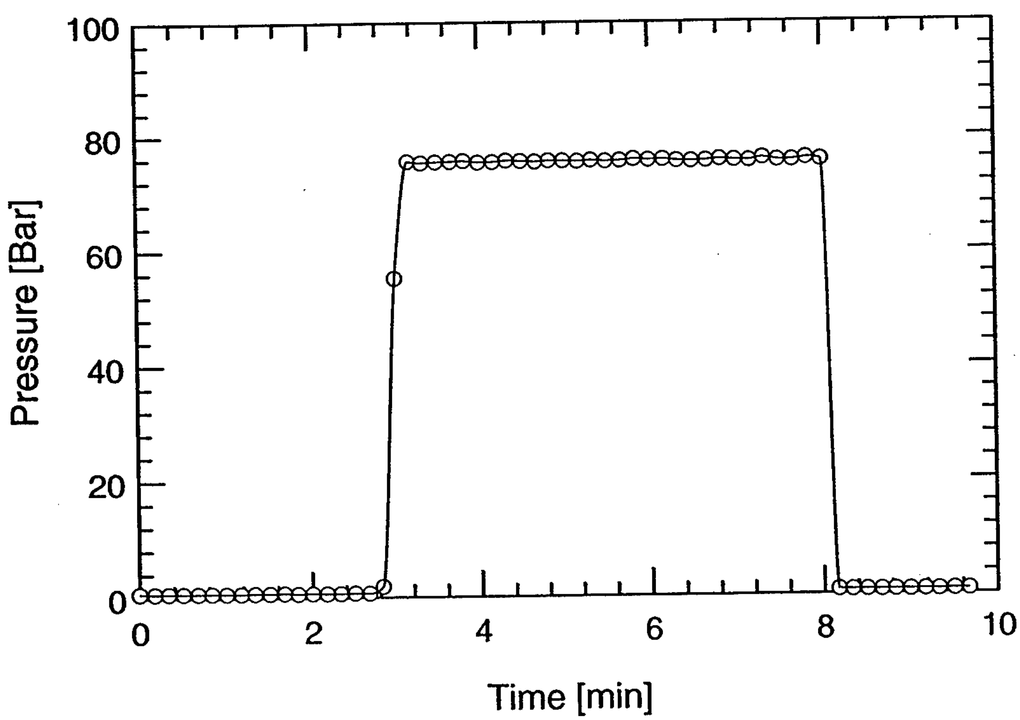


FR 22

Test #56

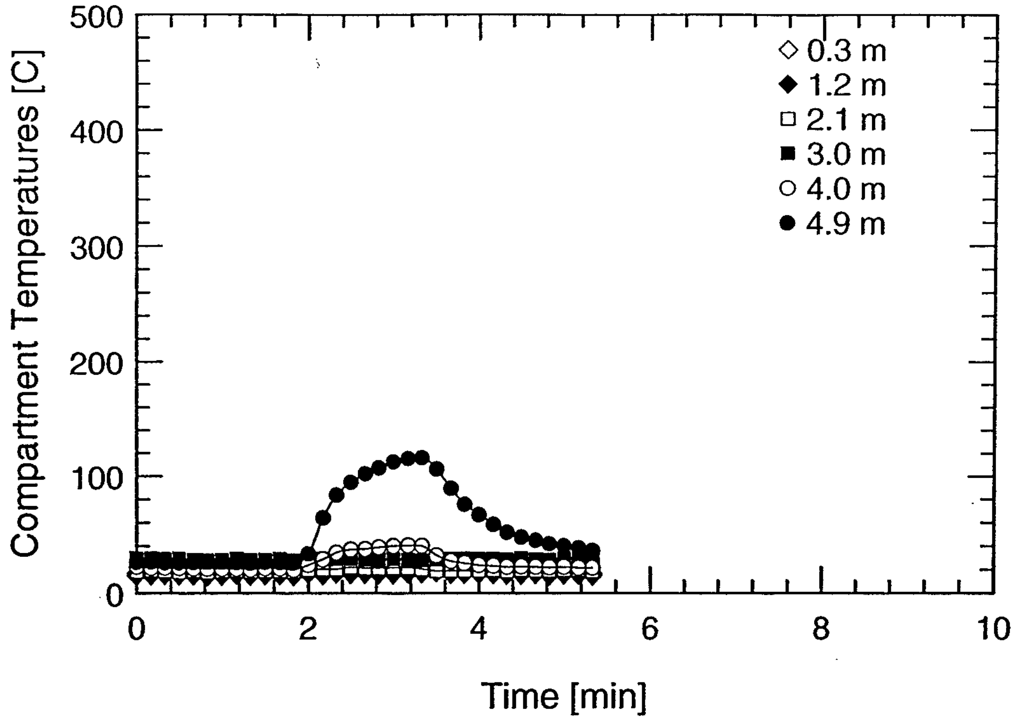


Water Mist System Flow Rate

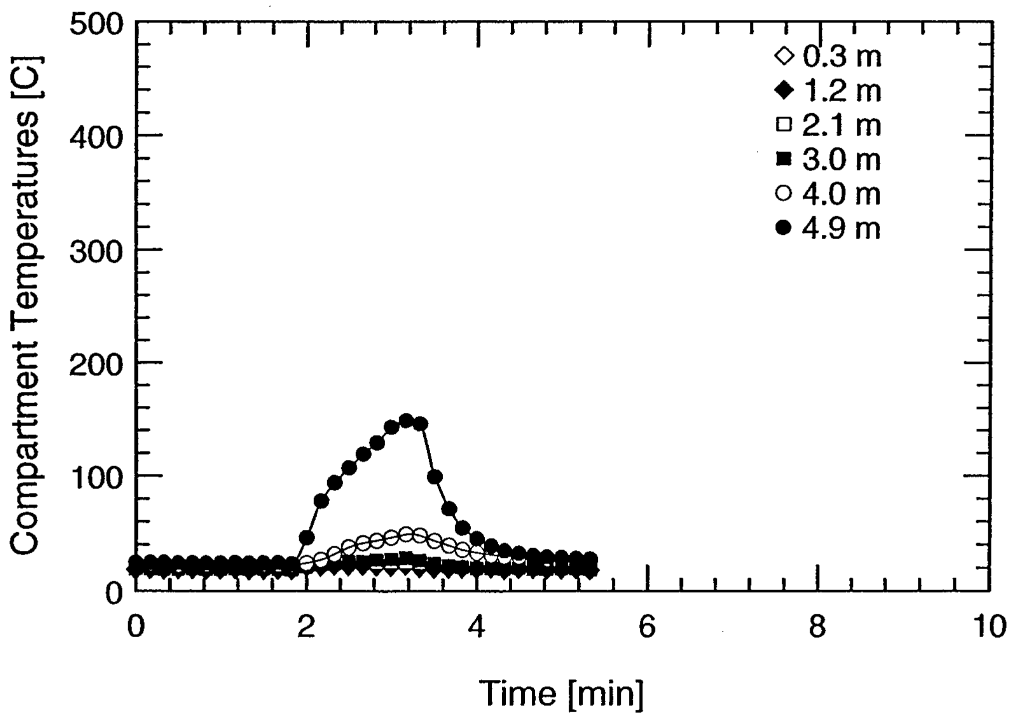


Water Mist System Pressure

Test #56

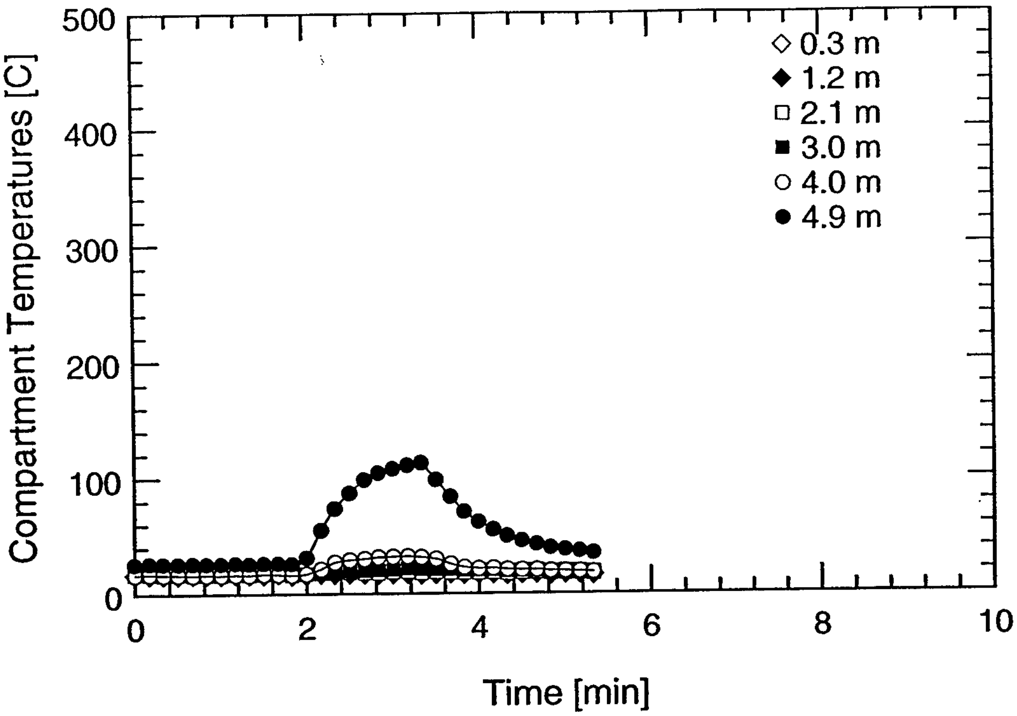


5-22-1

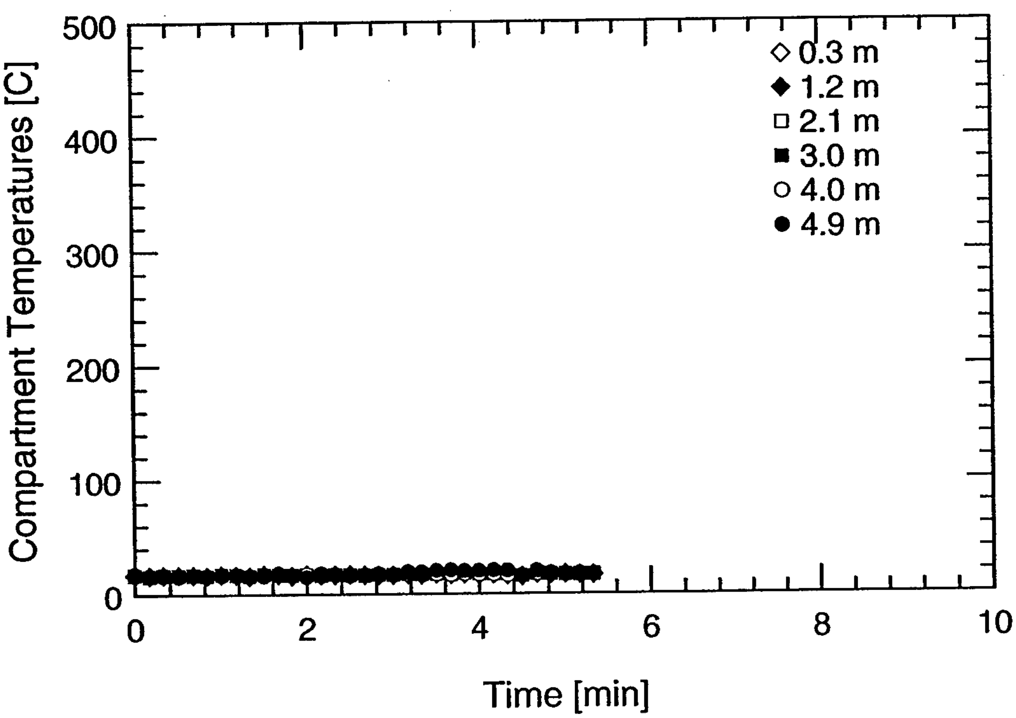


5-27-1

Test #57

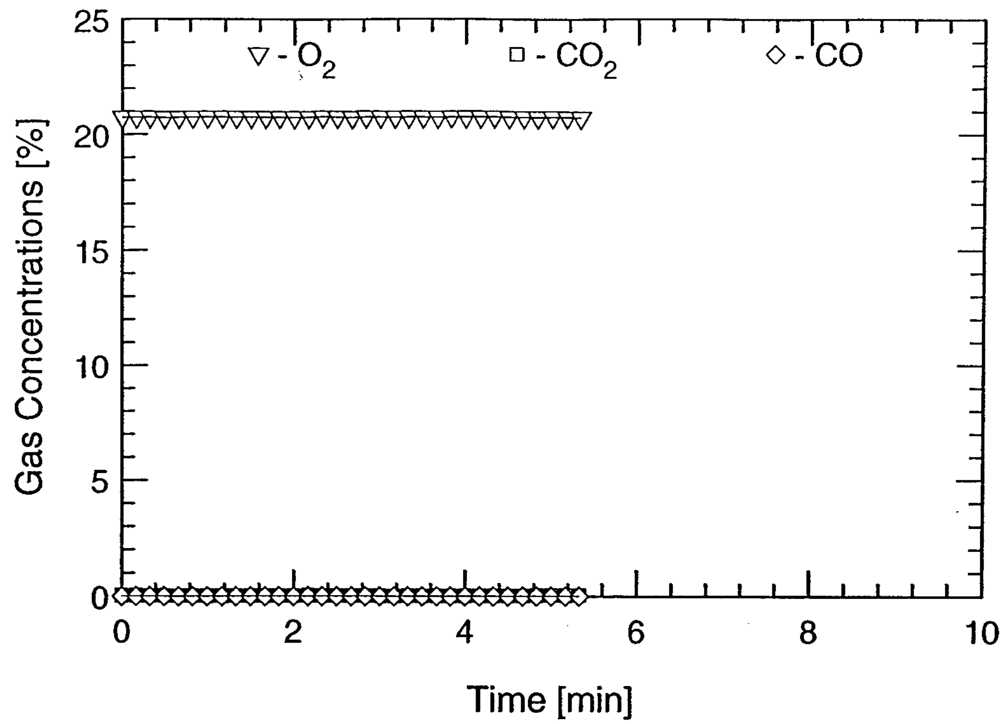


5-27-2

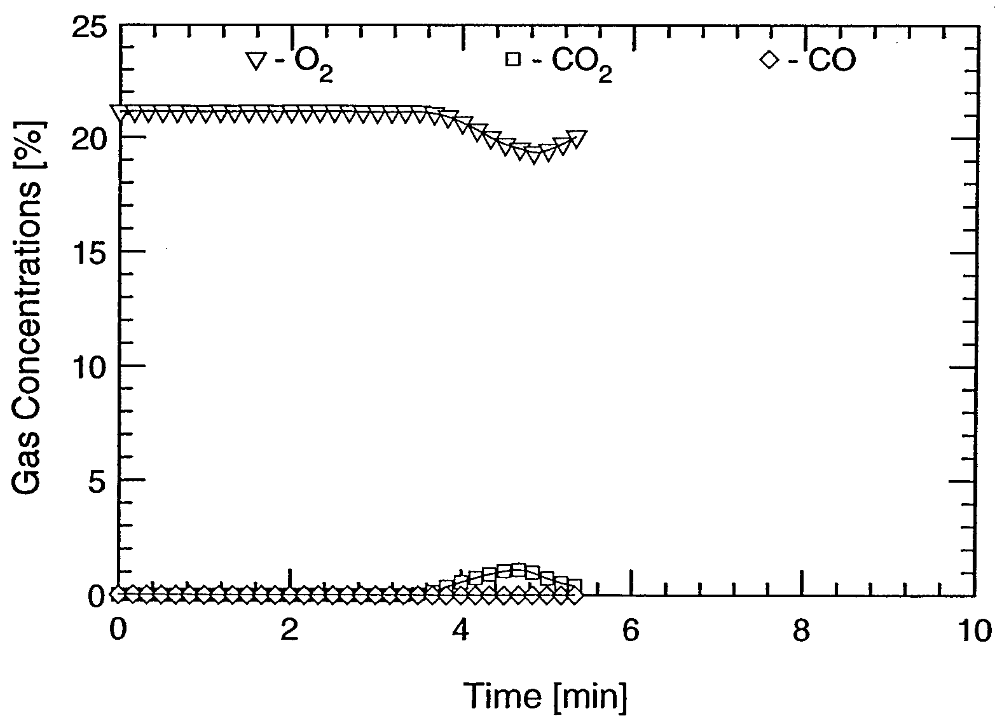


5-35-1

Test #57

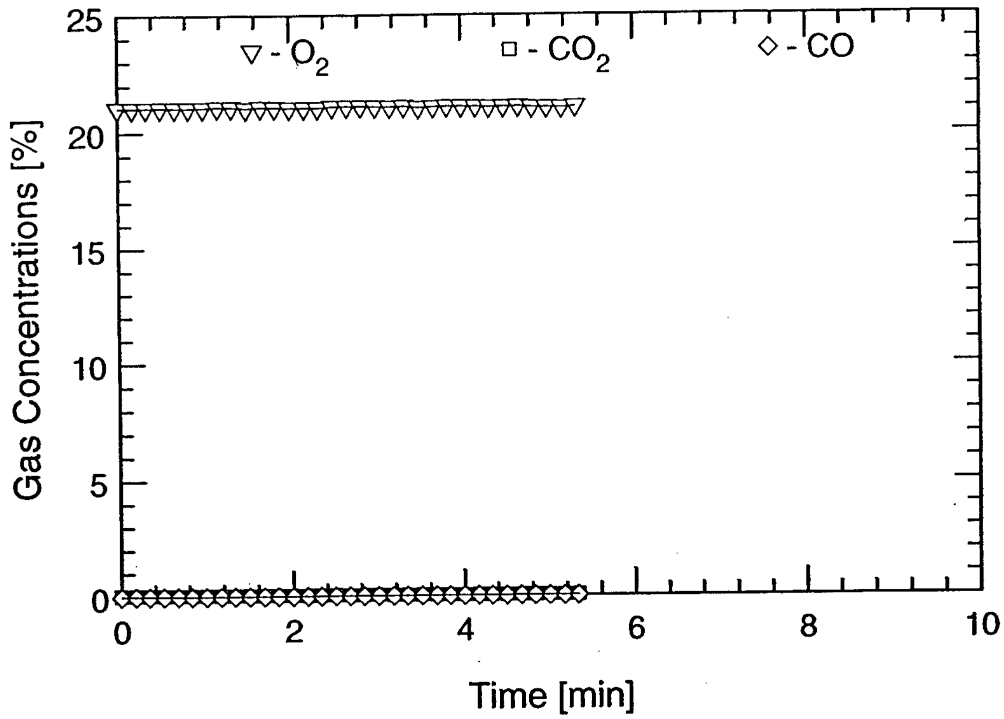


FR 22 - 0.5 m

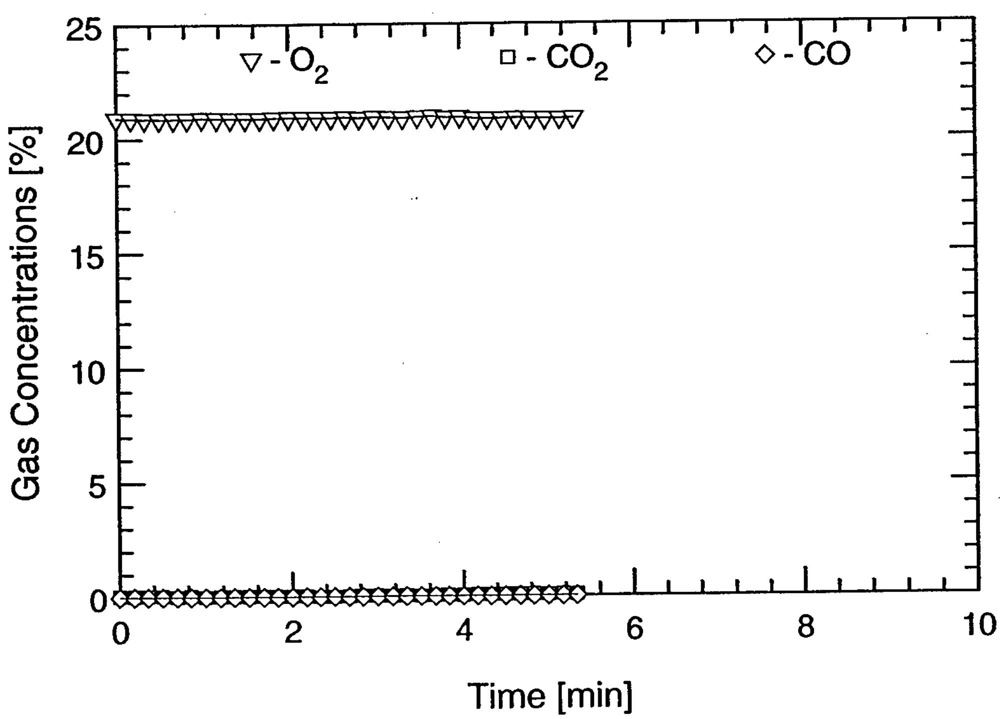


FR 22 - 4.5 m

Test #57

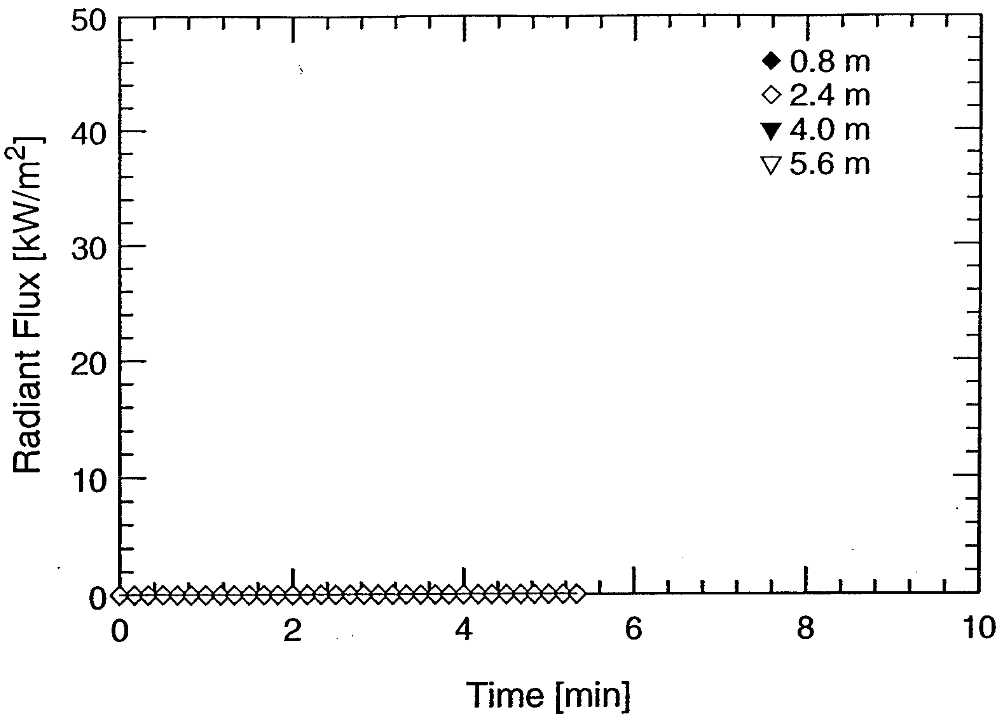


FR 36 - 0.5 m

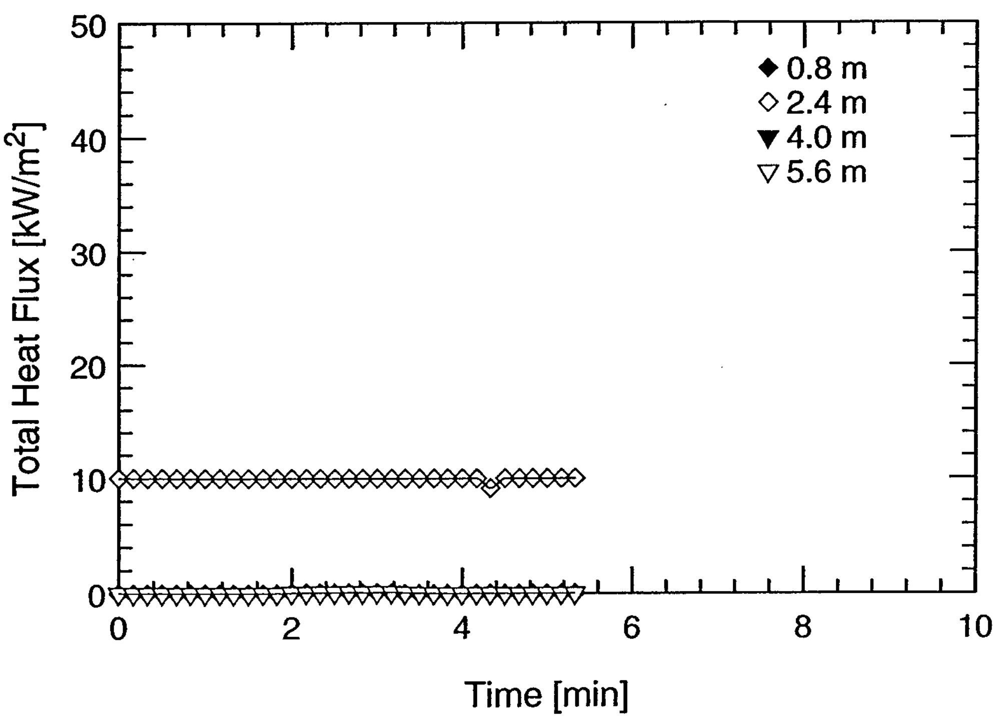


FR 36 - 4.5 m

Test #57

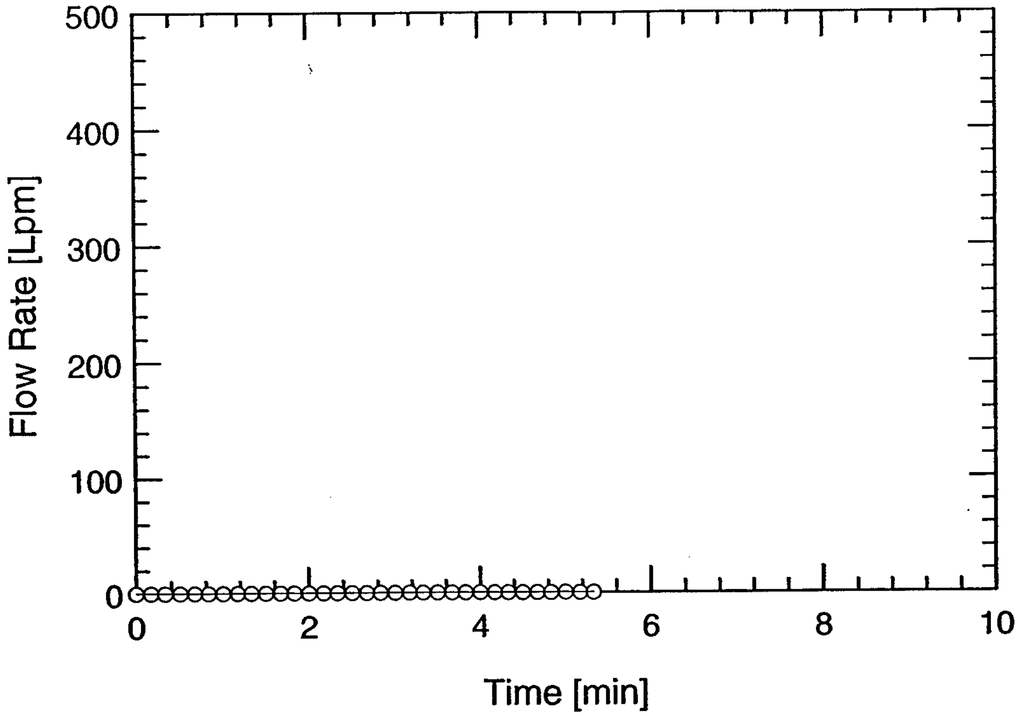


FR 22

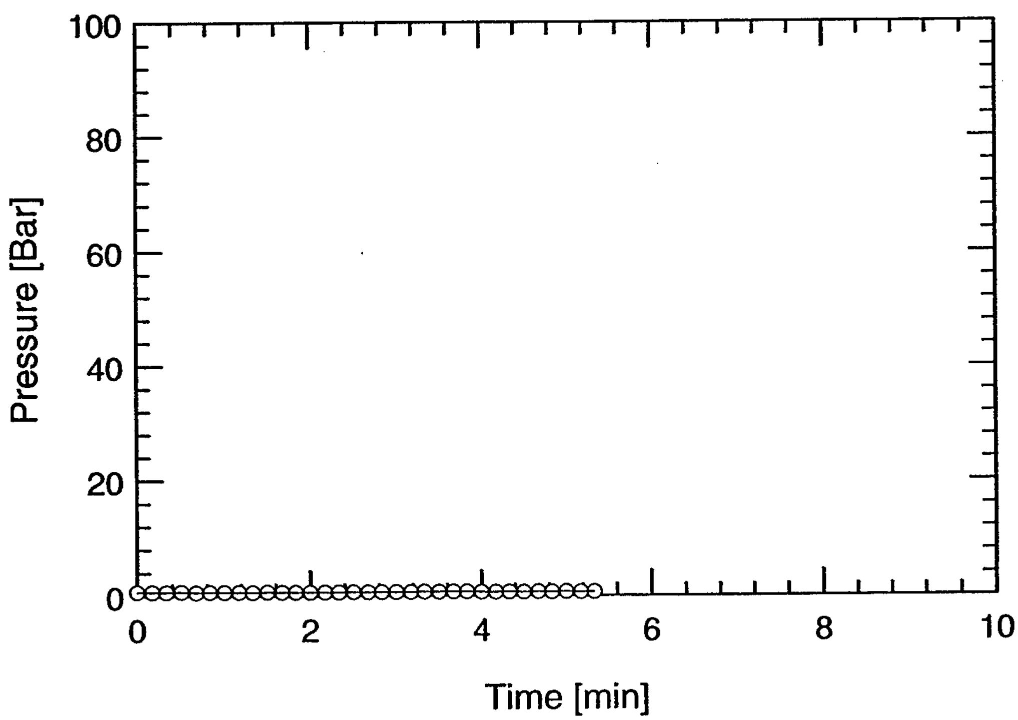


FR 22

Test #57

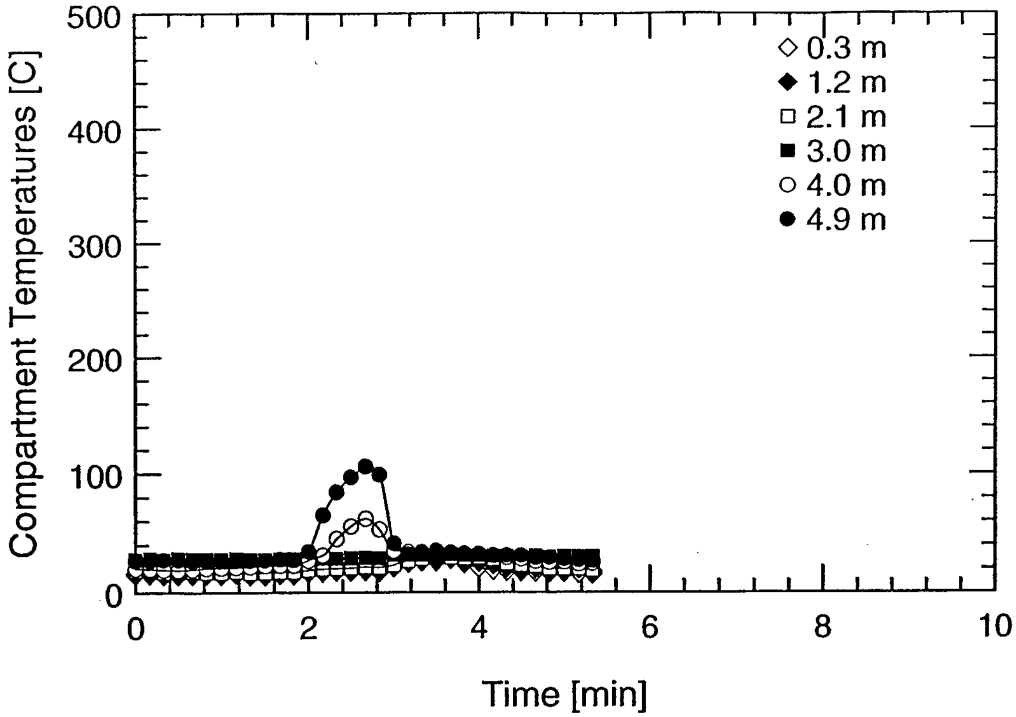


Water Mist System Flow Rate

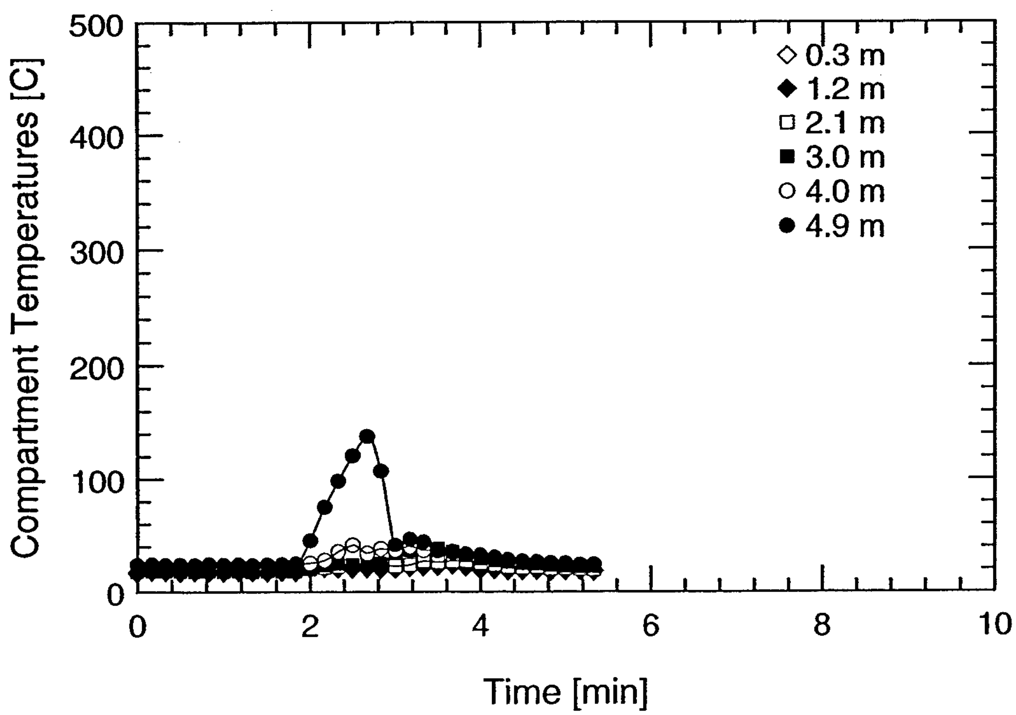


Water Mist System Pressure

Test #57

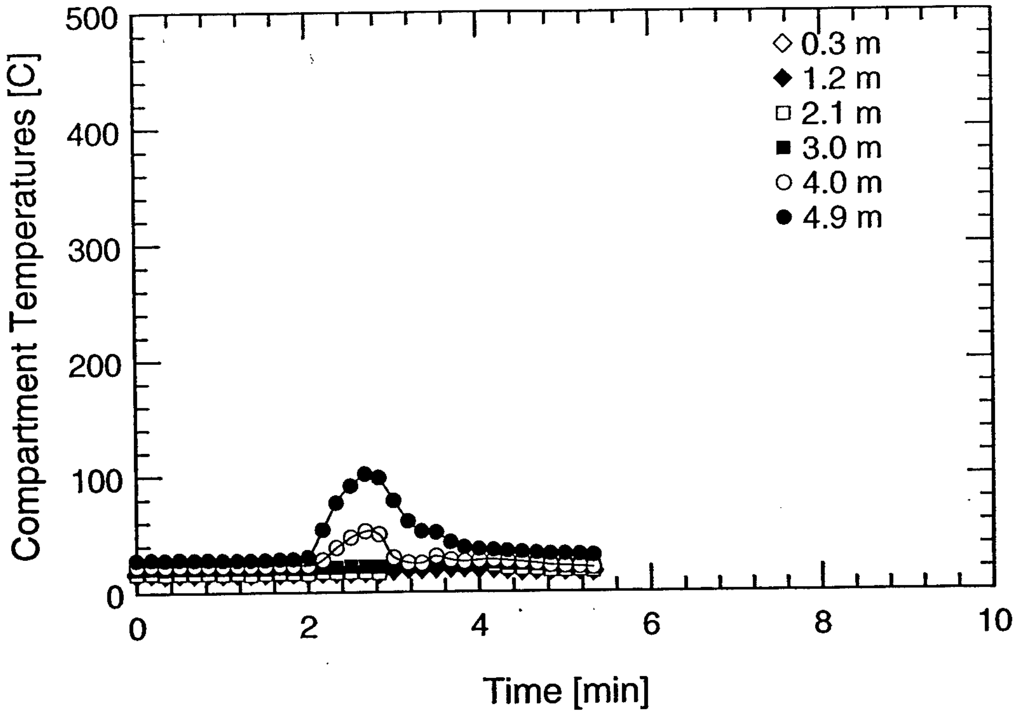


5-22-1

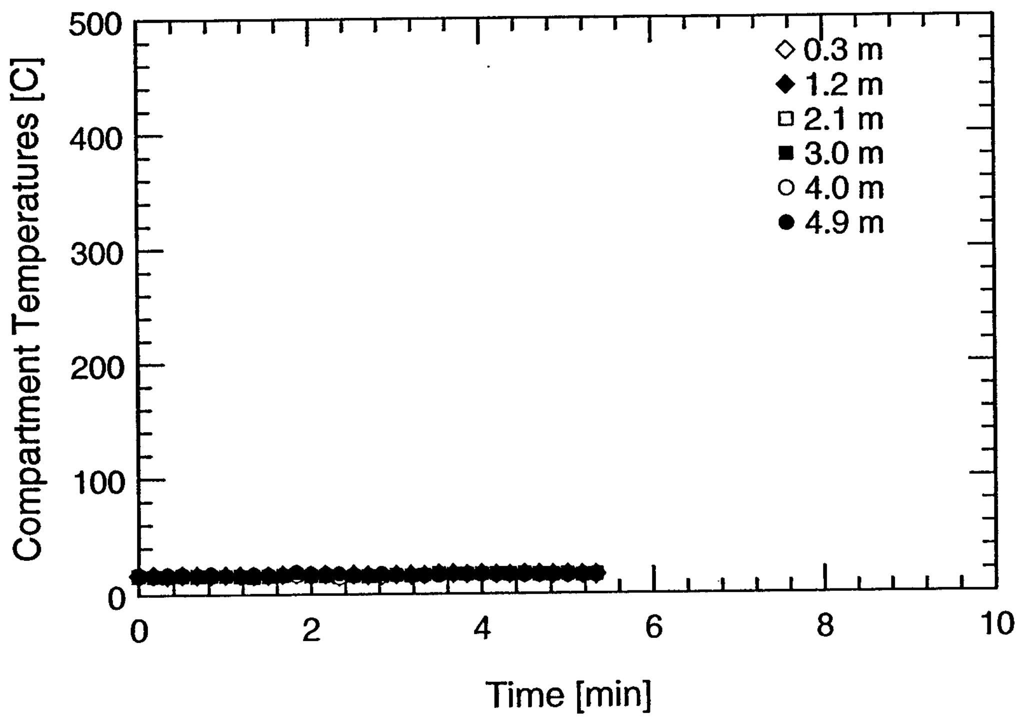


5-27-1

Test #58

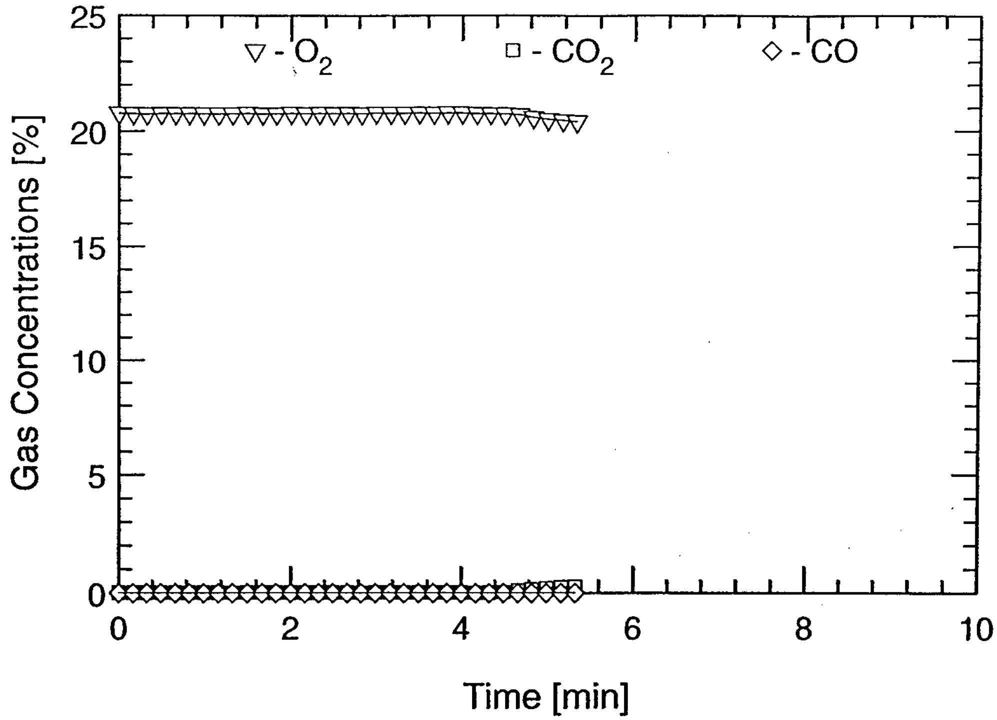


5-27-2

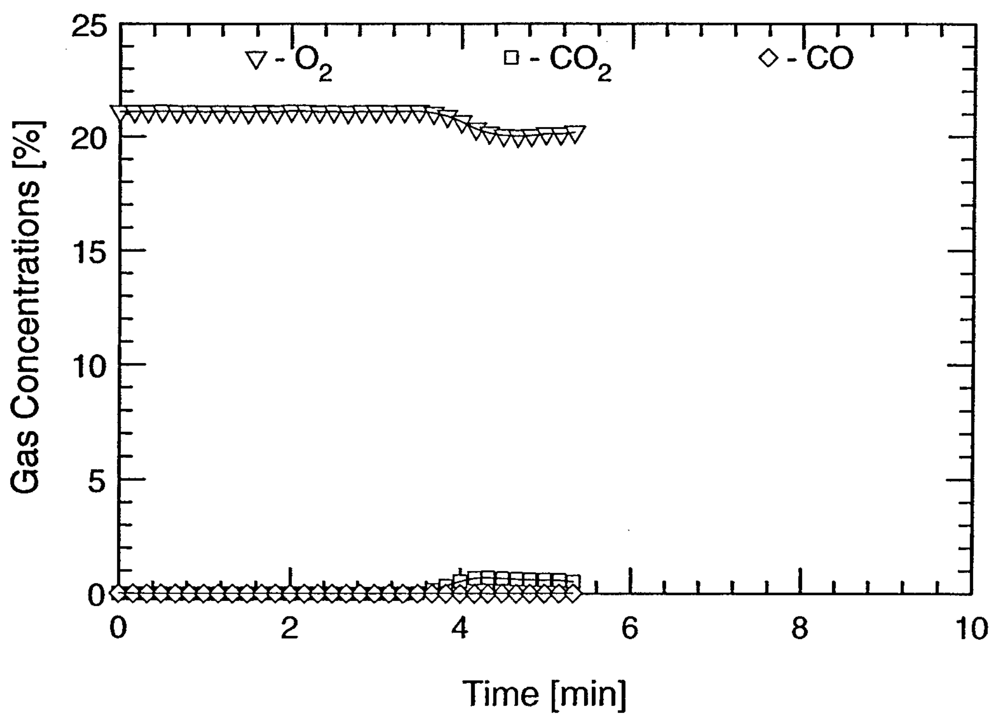


5-35-1

Test #58

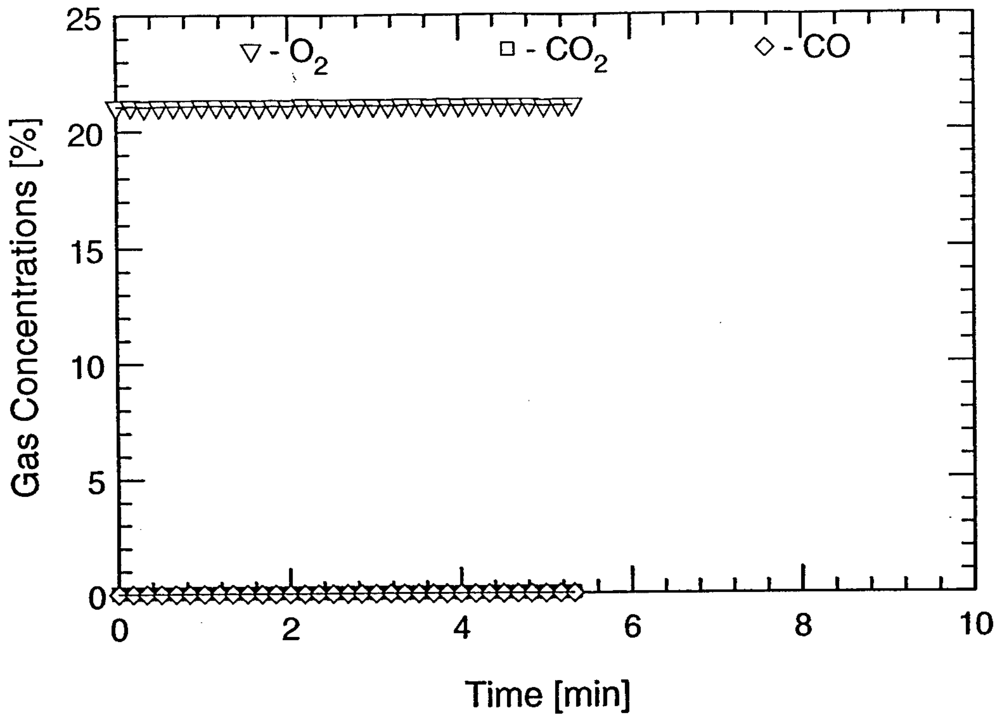


FR 22 - 0.5 m

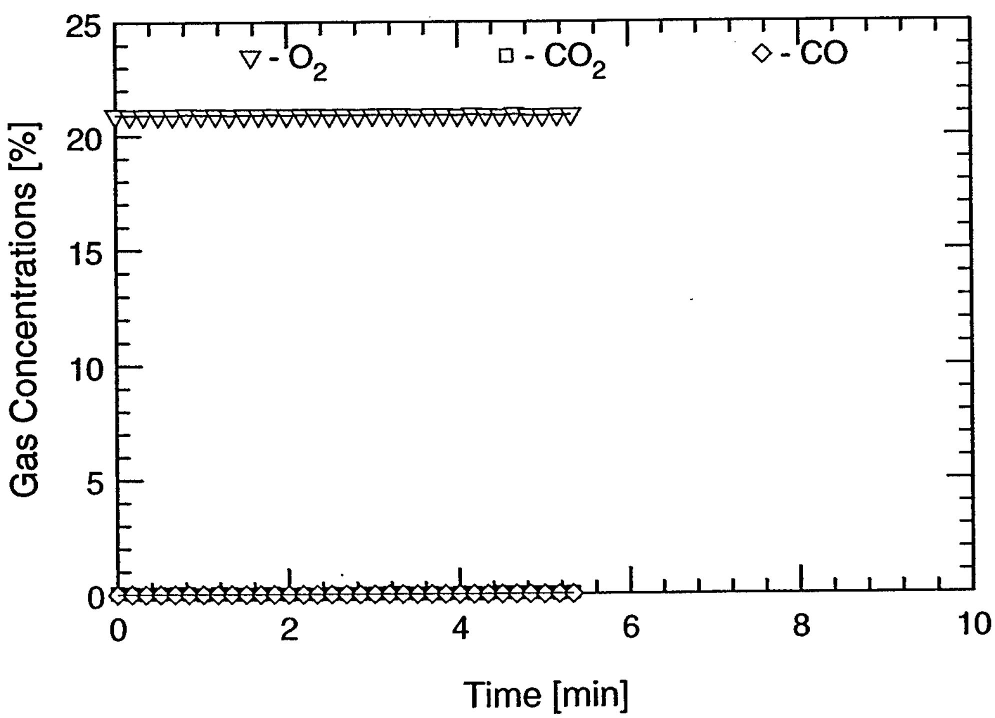


FR 22 - 4.5 m

Test #58

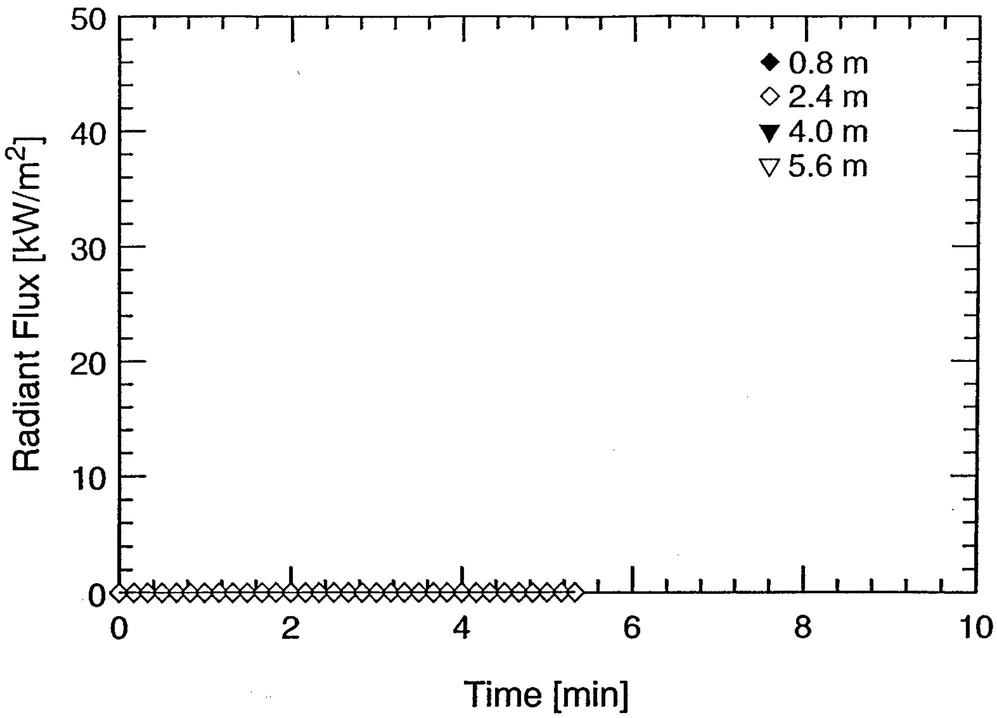


FR 36 - 0.5 m

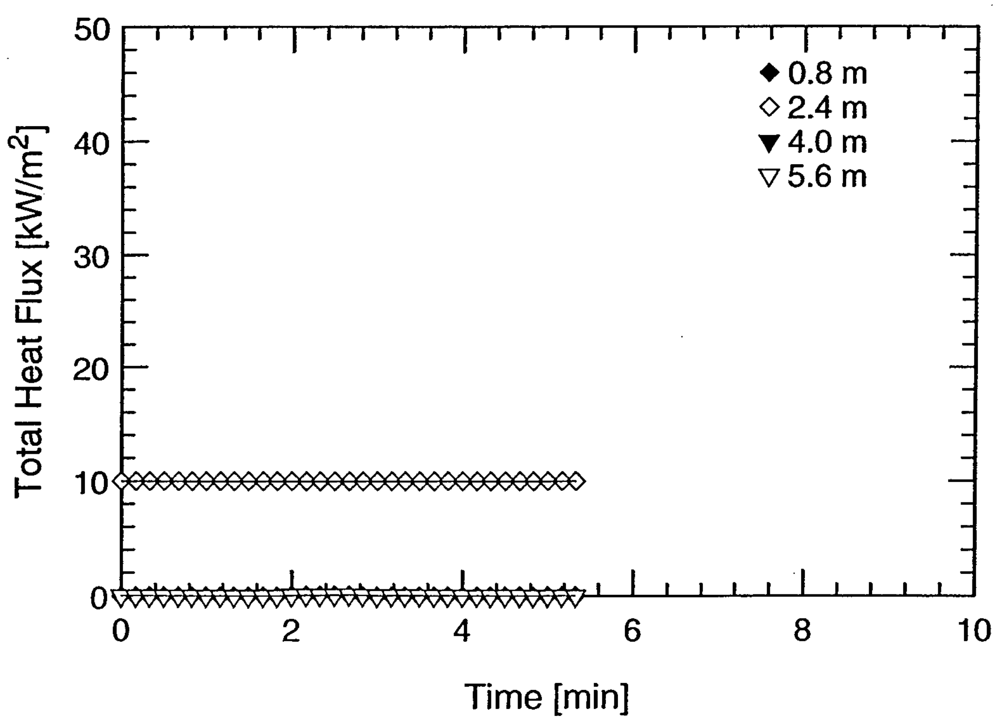


FR 36 - 4.5 m

Test #58

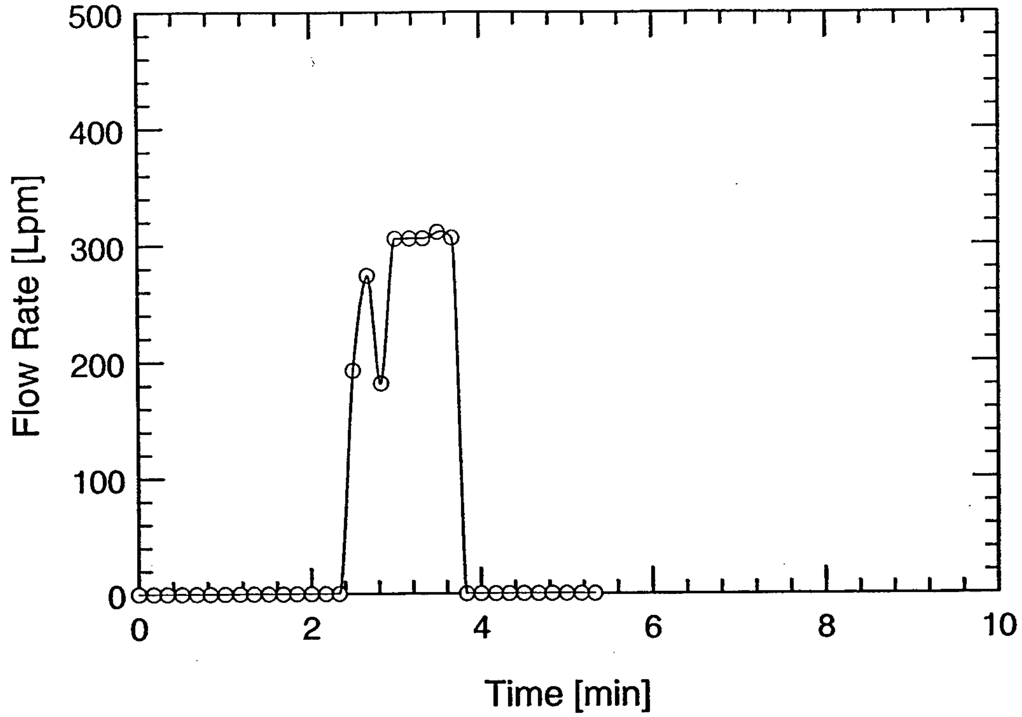


FR 22

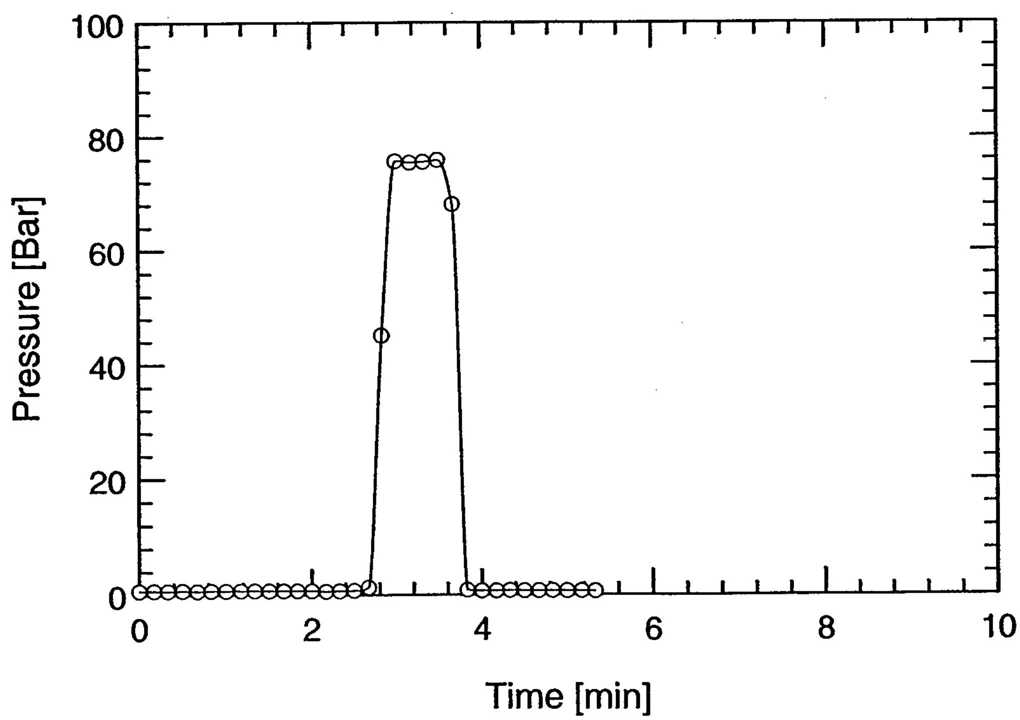


FR 22

Test #58

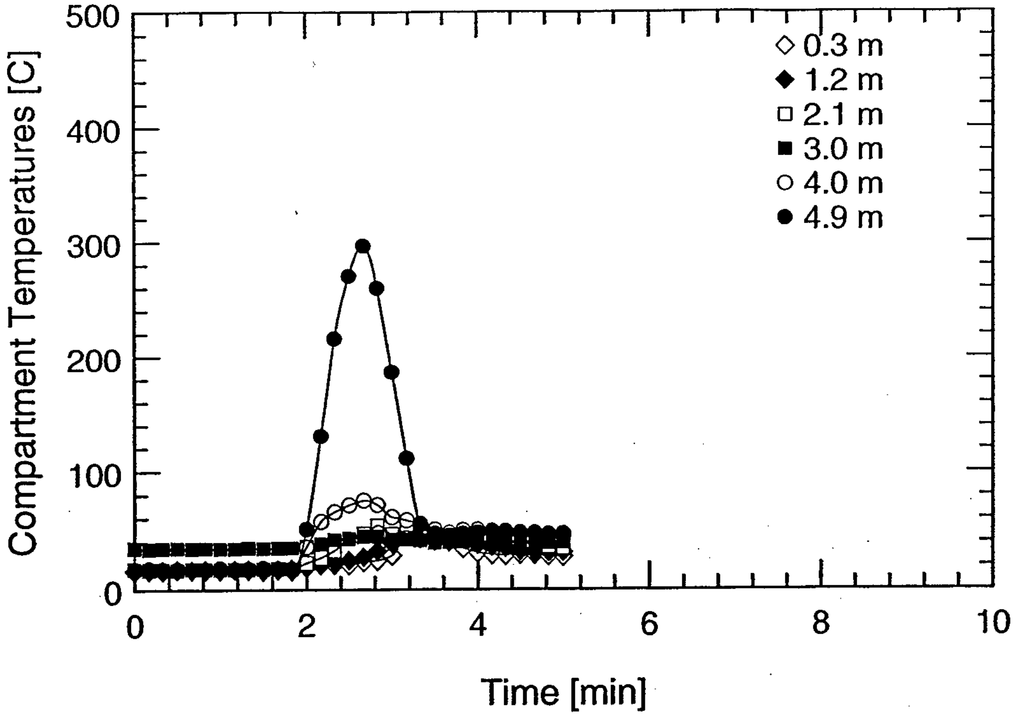


Water Mist System Flow Rate

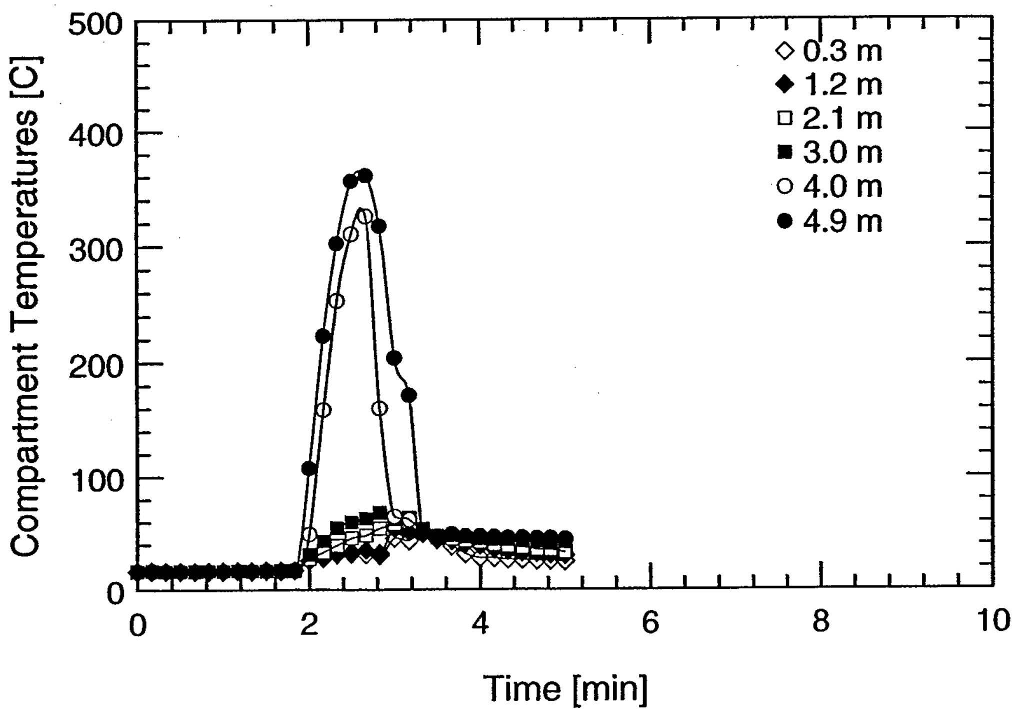


Water Mist System Pressure

Test #58

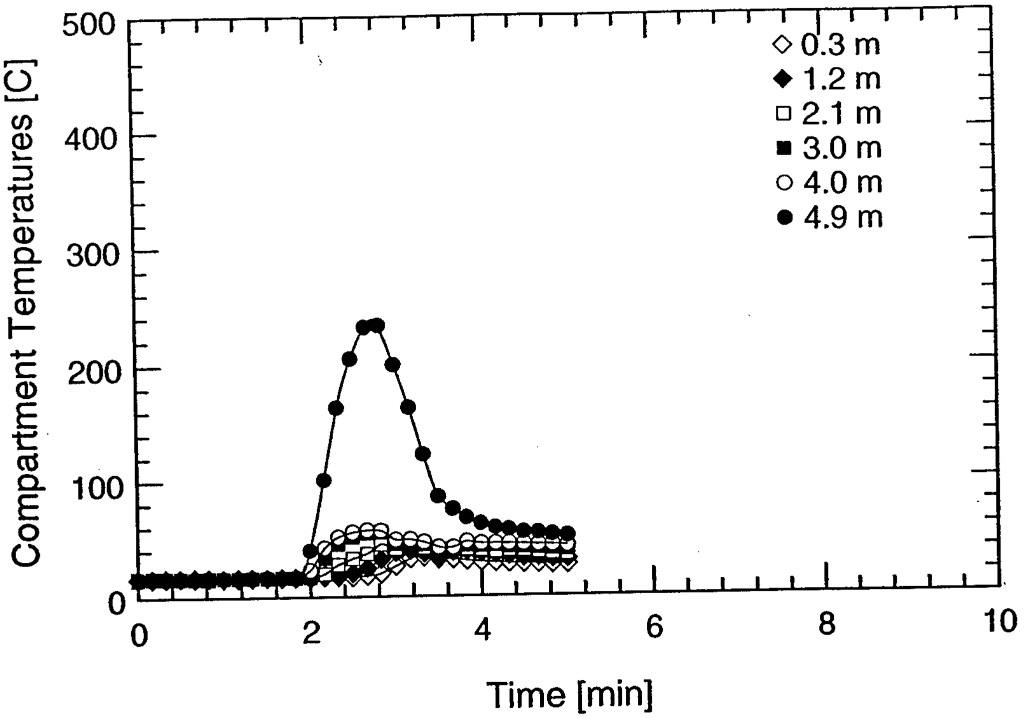


5-22-1

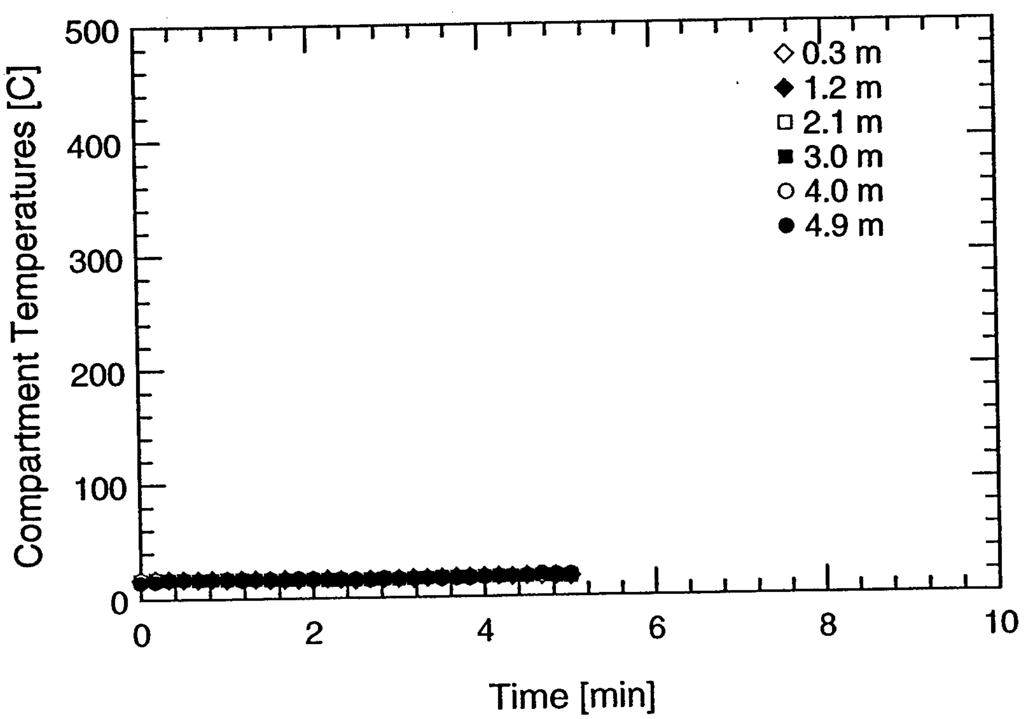


5-27-1

Test #59

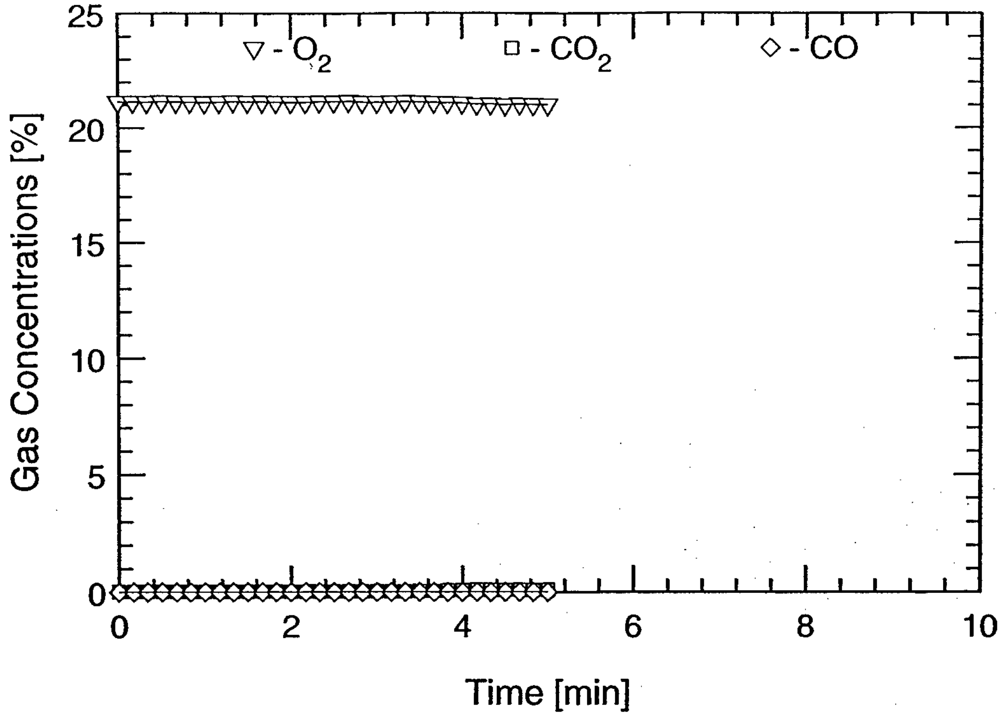


5-27-2

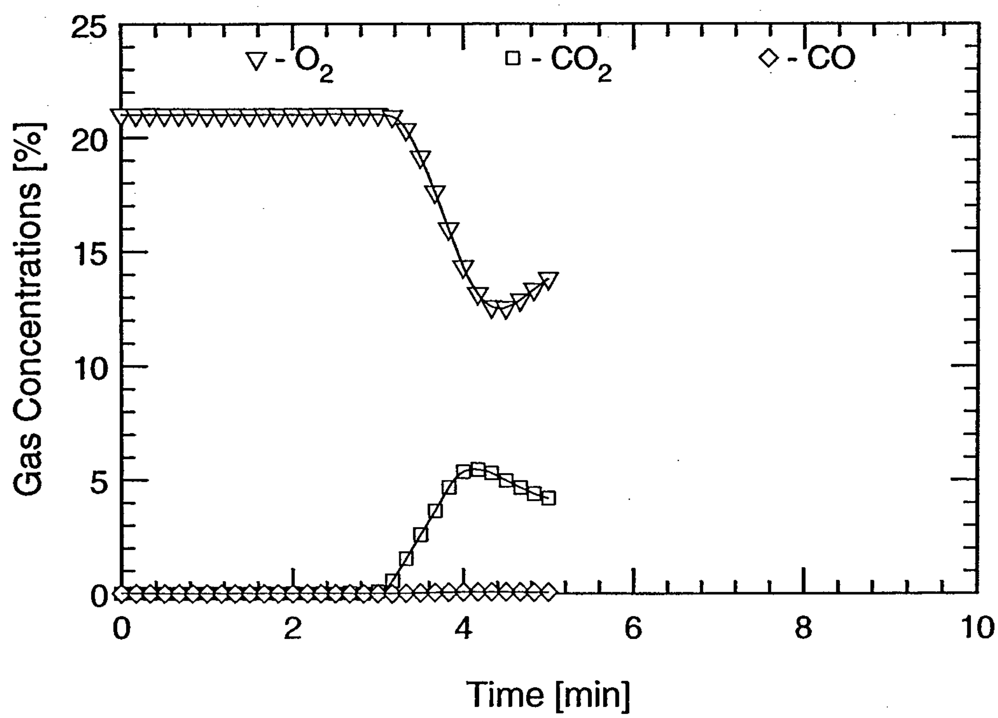


5-35-1

Test #59

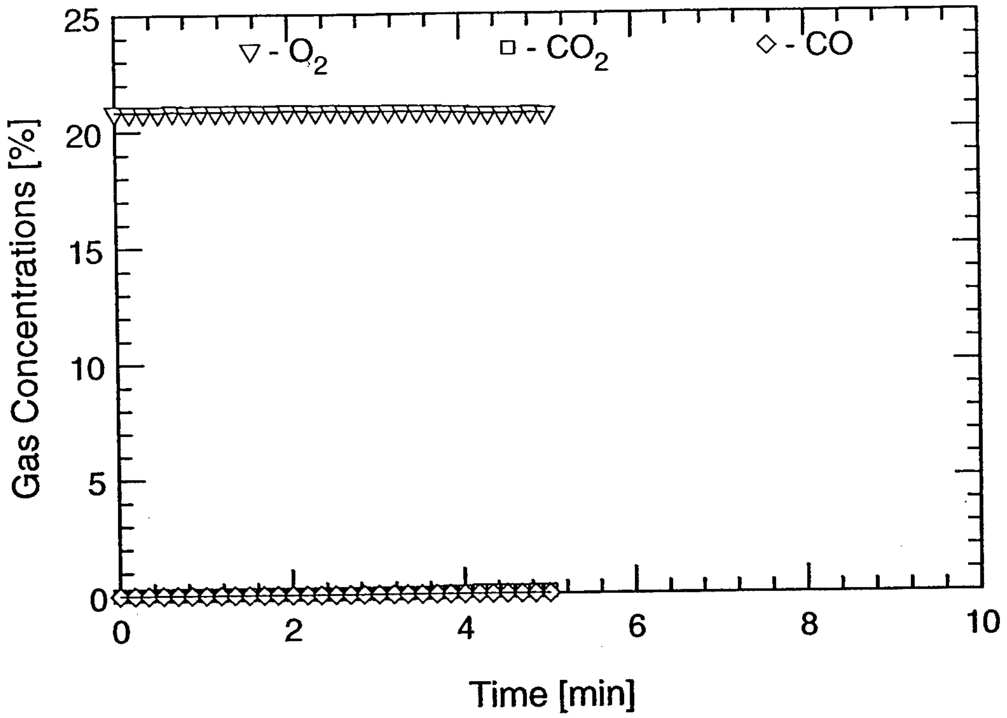


FR 22 - 0.5 m

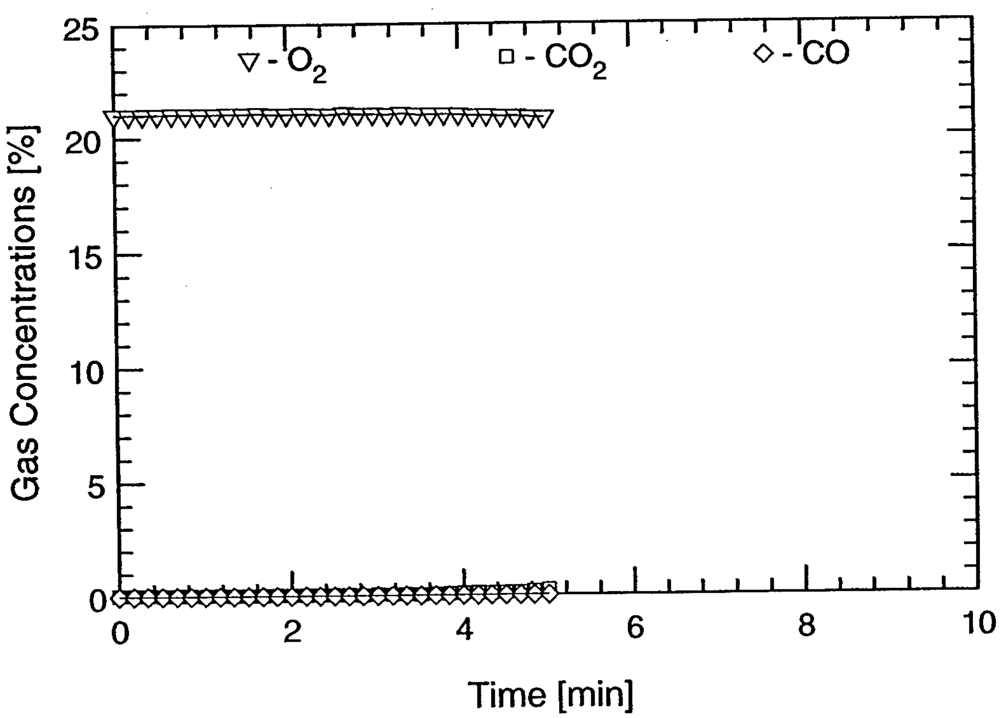


FR 22 - 4.5 m

Test #59

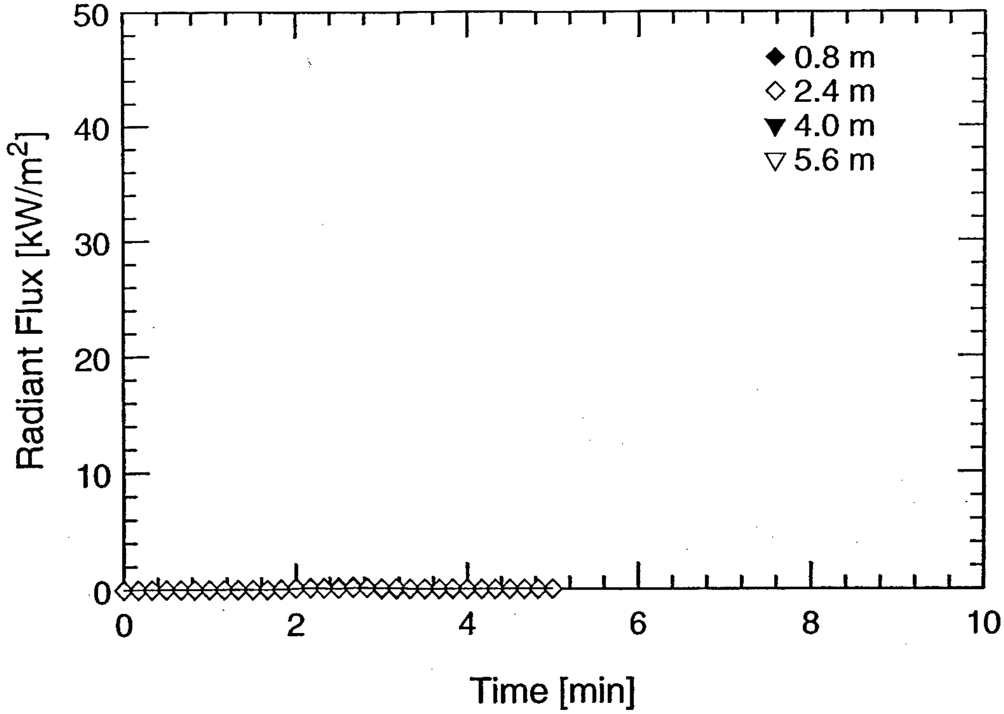


FR 36 - 0.5 m

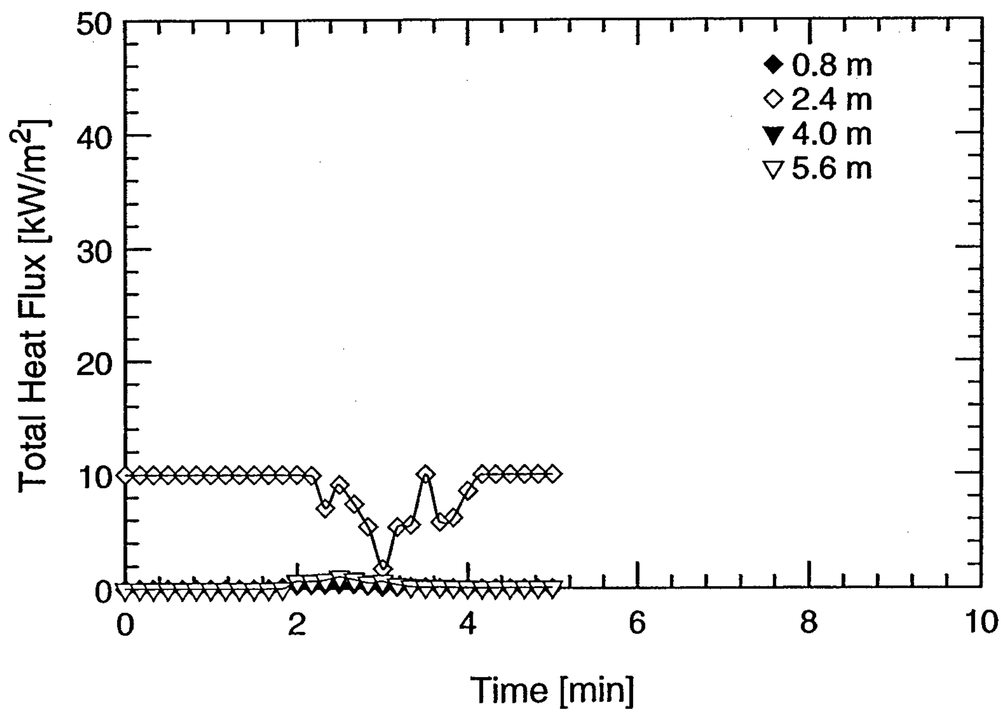


FR 36 - 4.5 m

Test #59

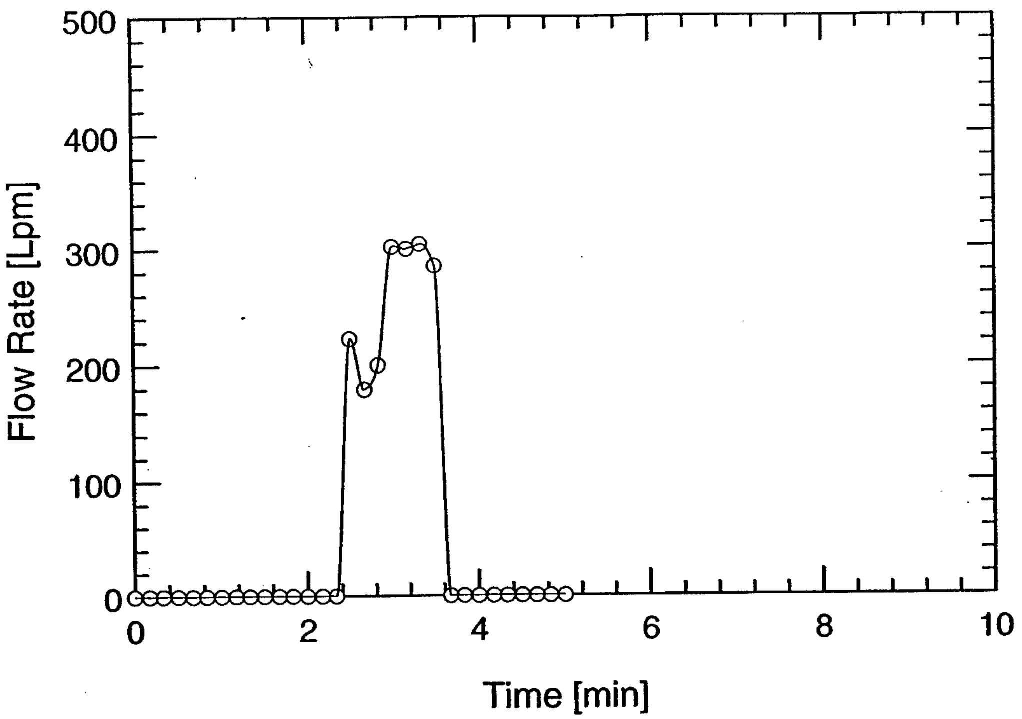


FR 22

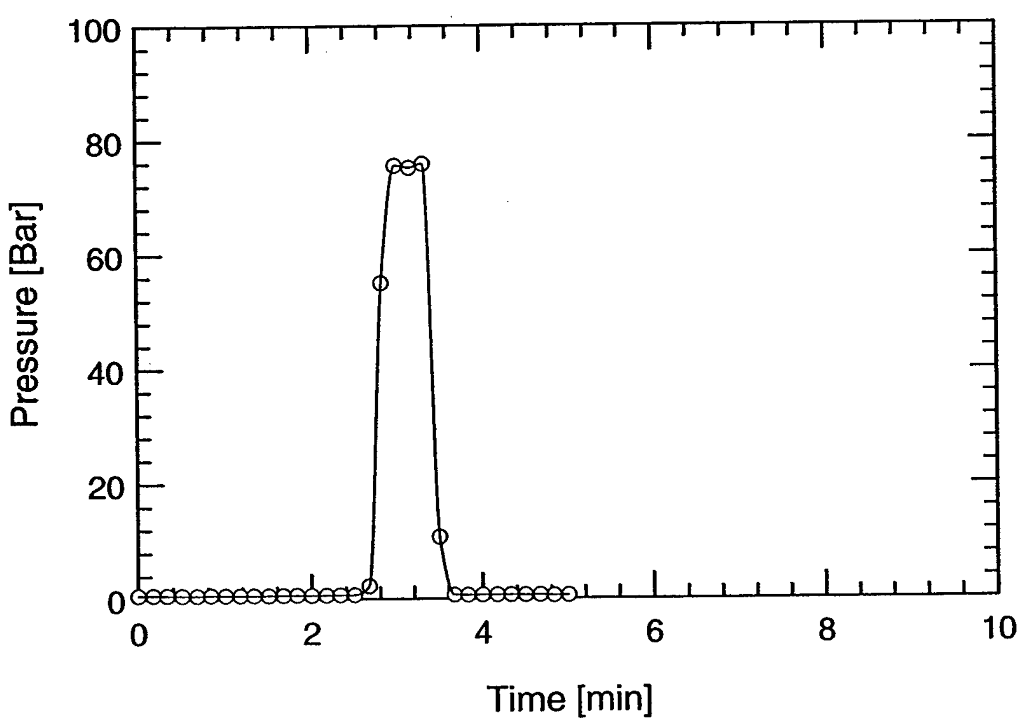


FR 22

Test #59

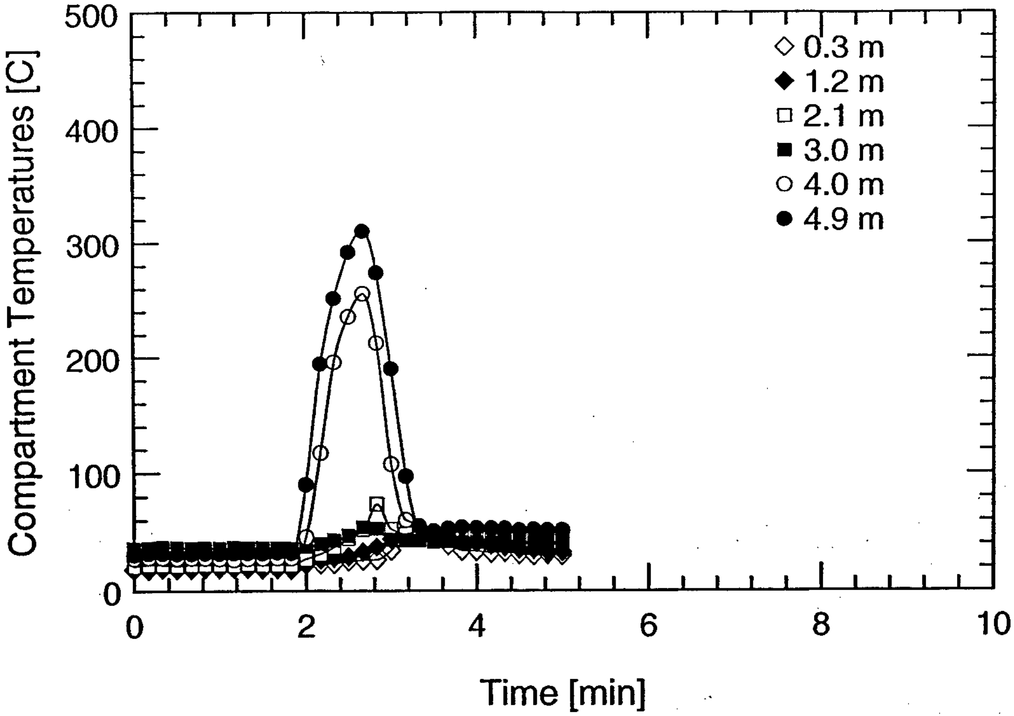


Water Mist System Flow Rate

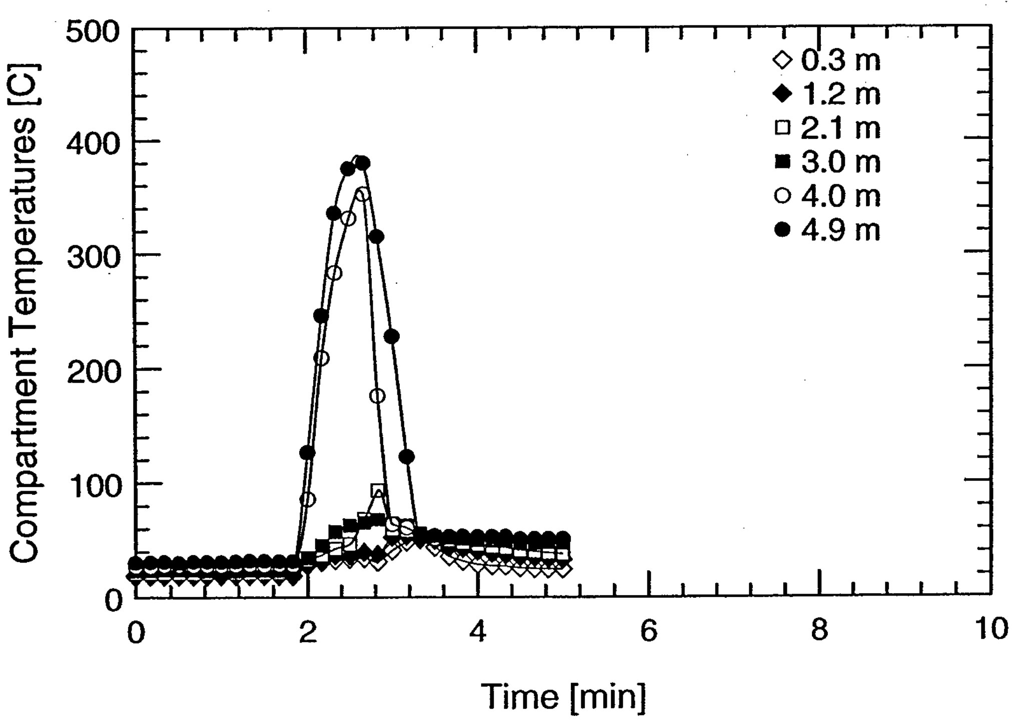


Water Mist System Pressure

Test #59

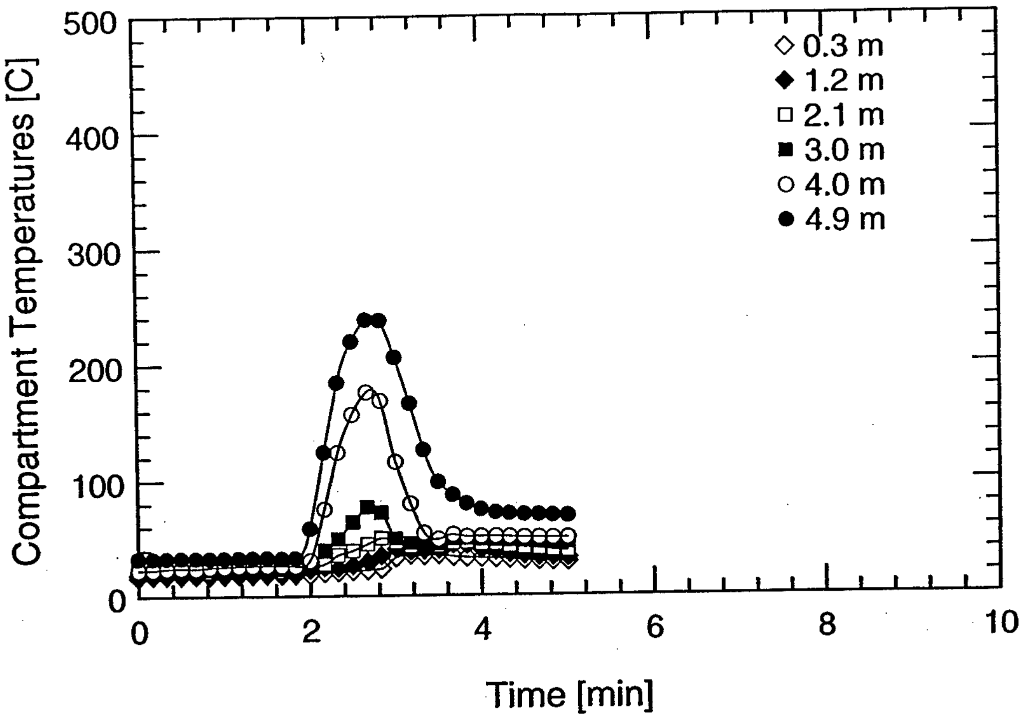


5-22-1

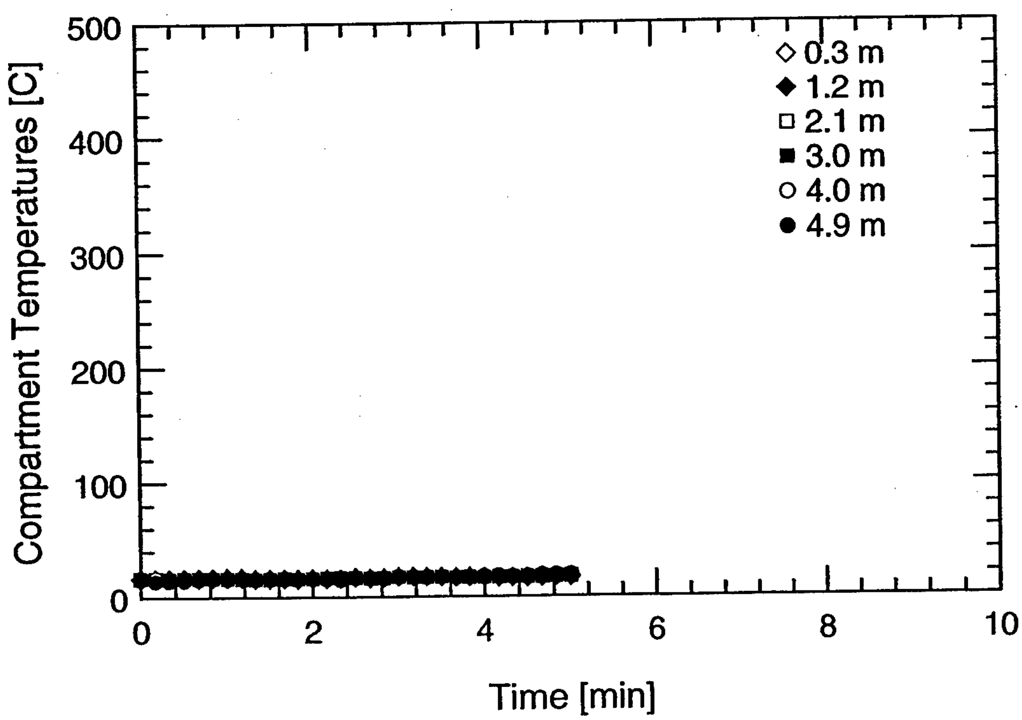


5-27-1

Test #60

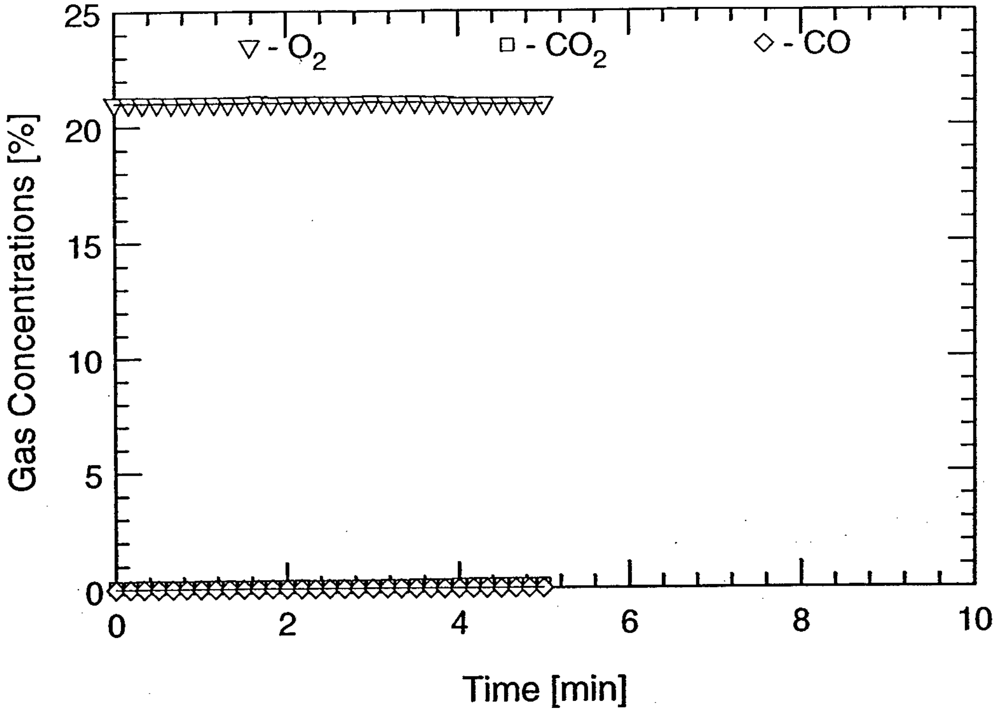


5-27-2

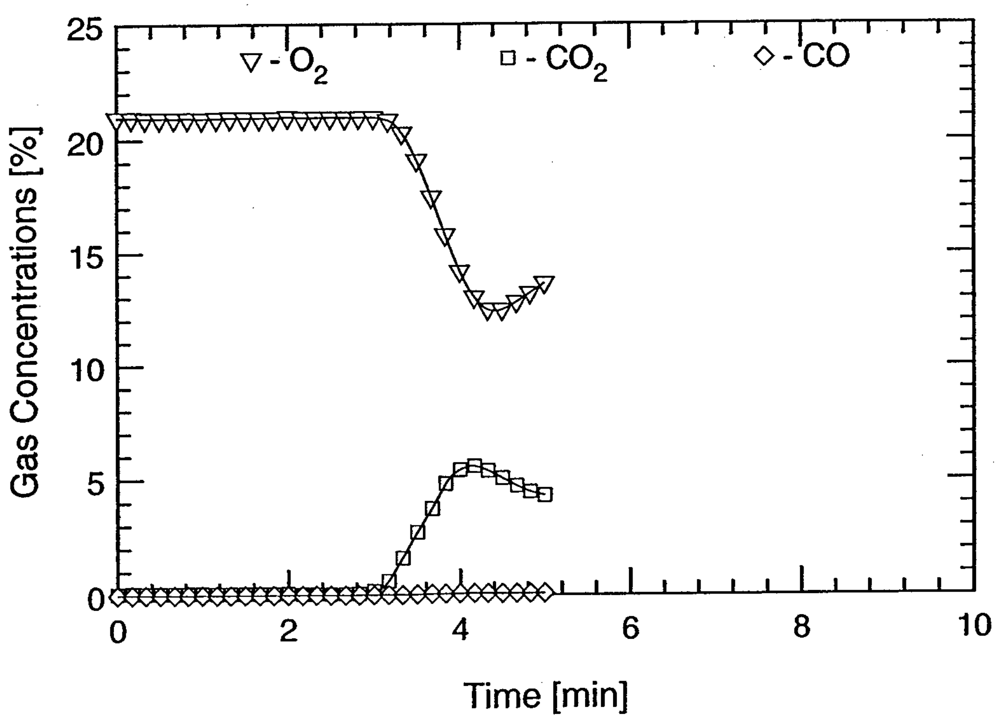


5-35-1

Test #60

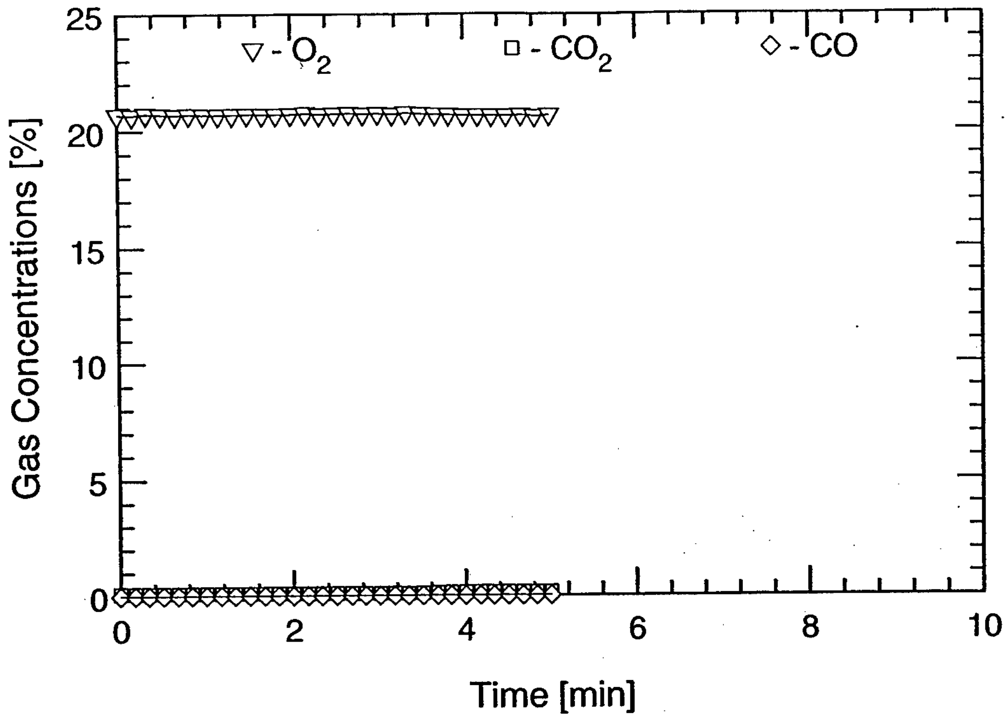


FR 22 - 0.5 m

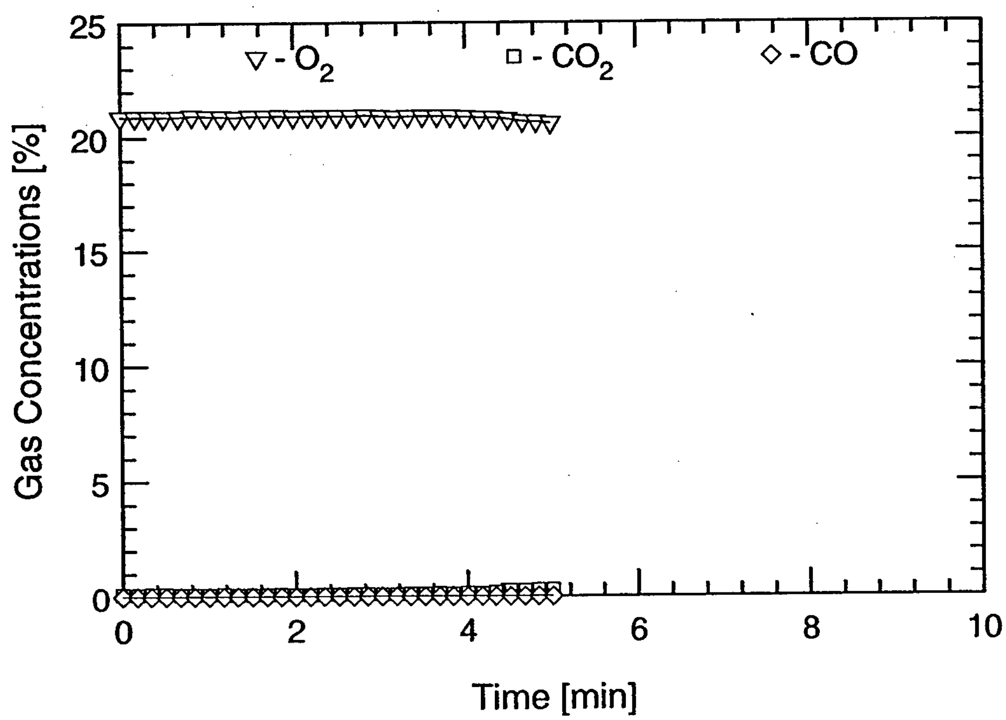


FR 22 - 4.5 m

Test #60

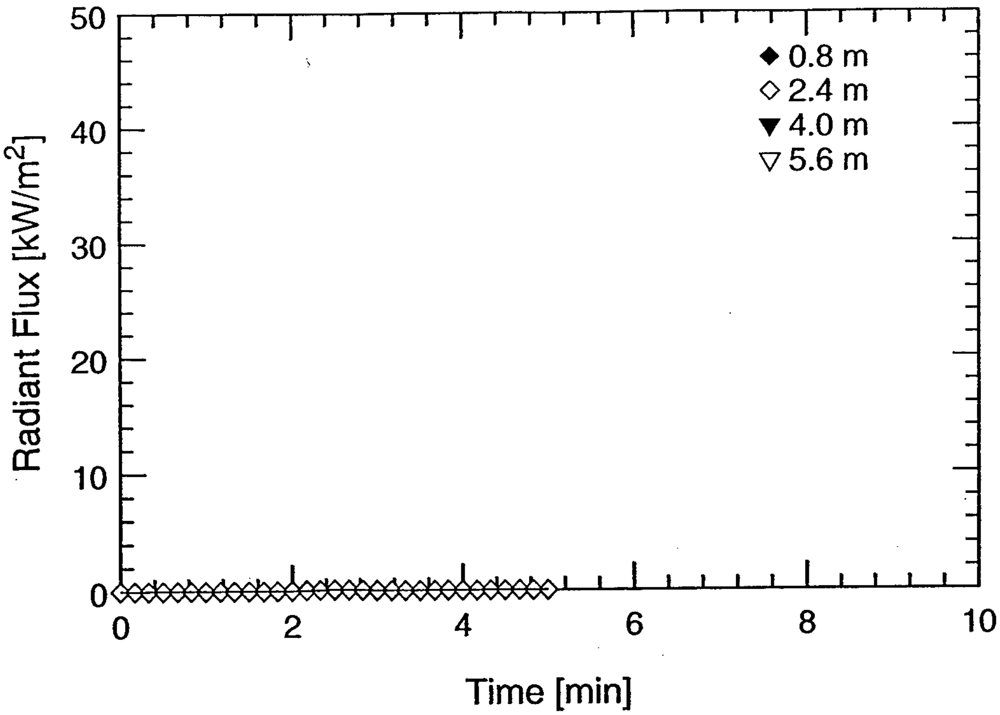


FR 36 - 0.5 m

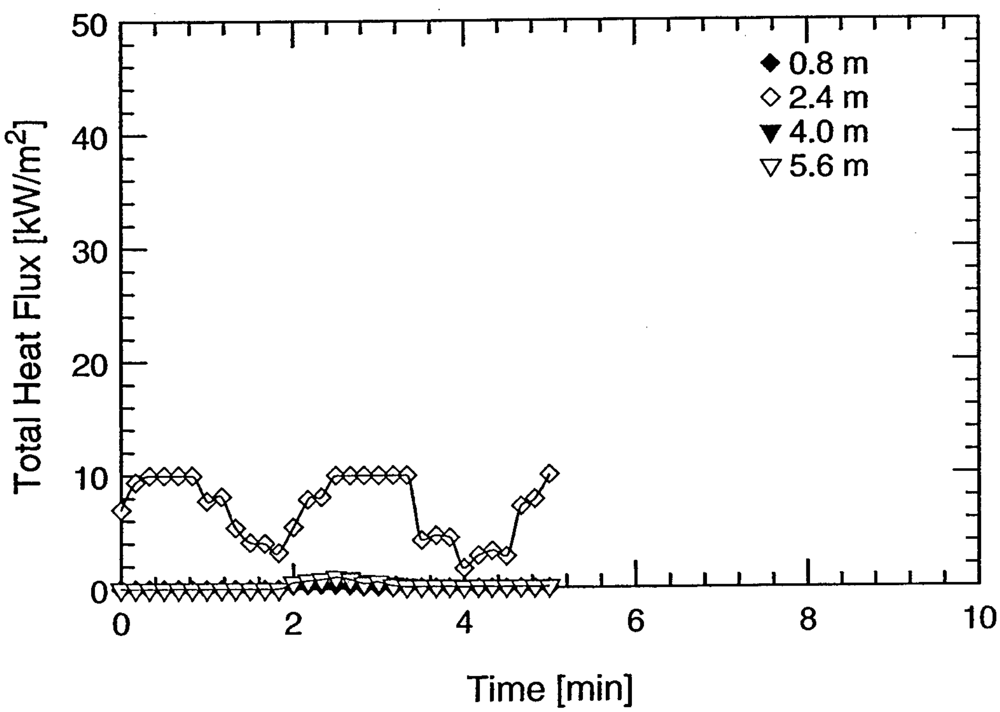


FR 36 - 4.5 m

Test #60



FR 22



FR 22

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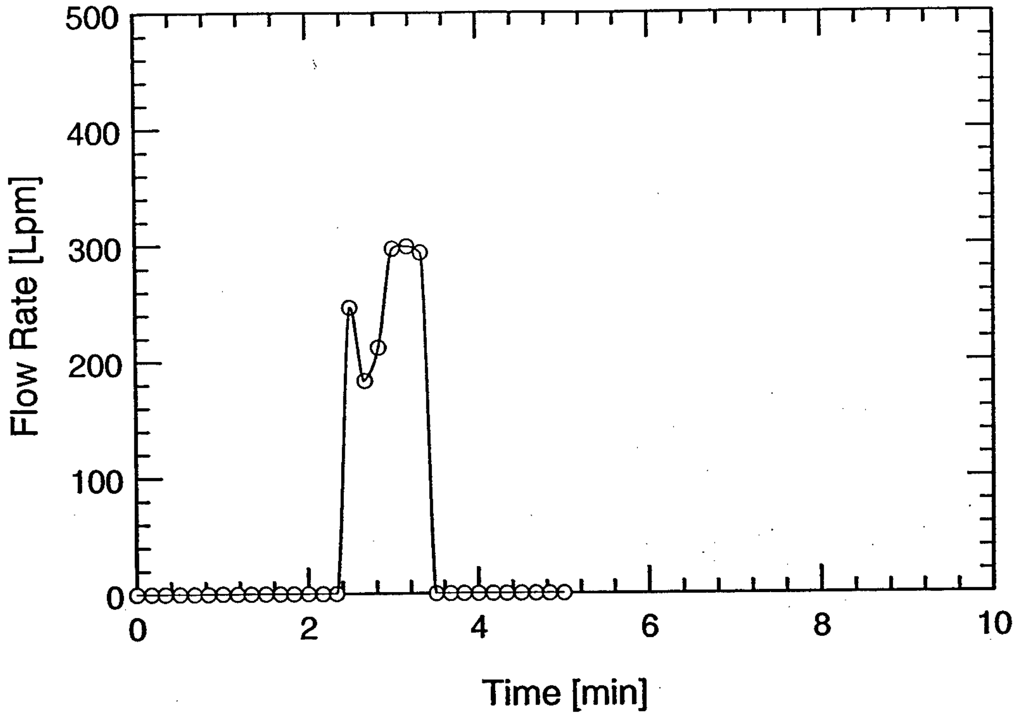
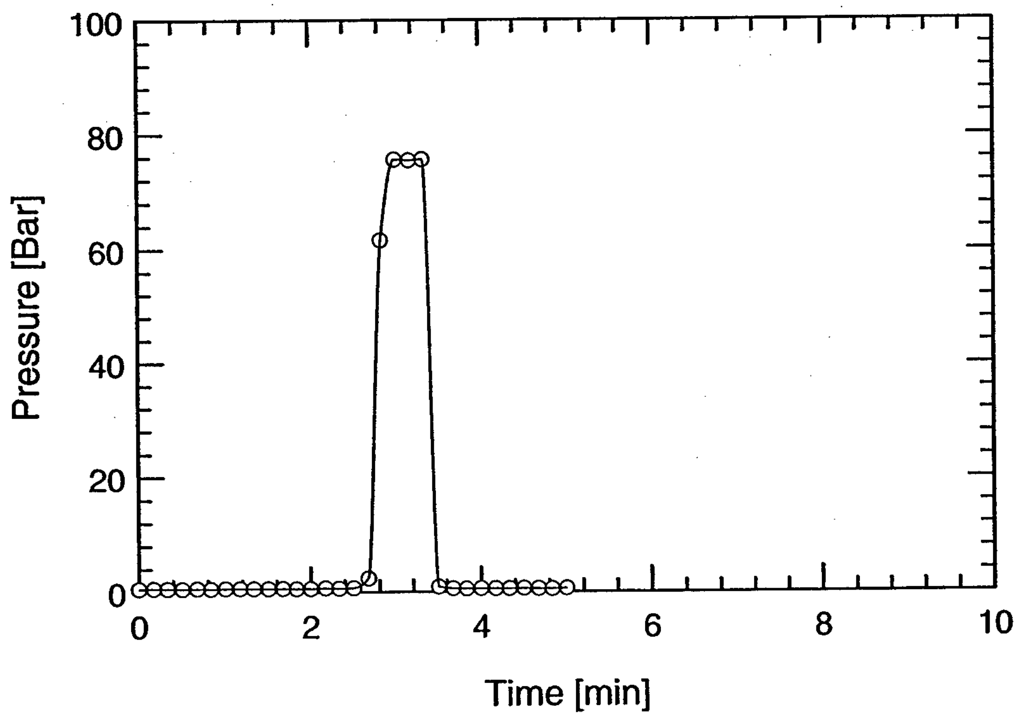
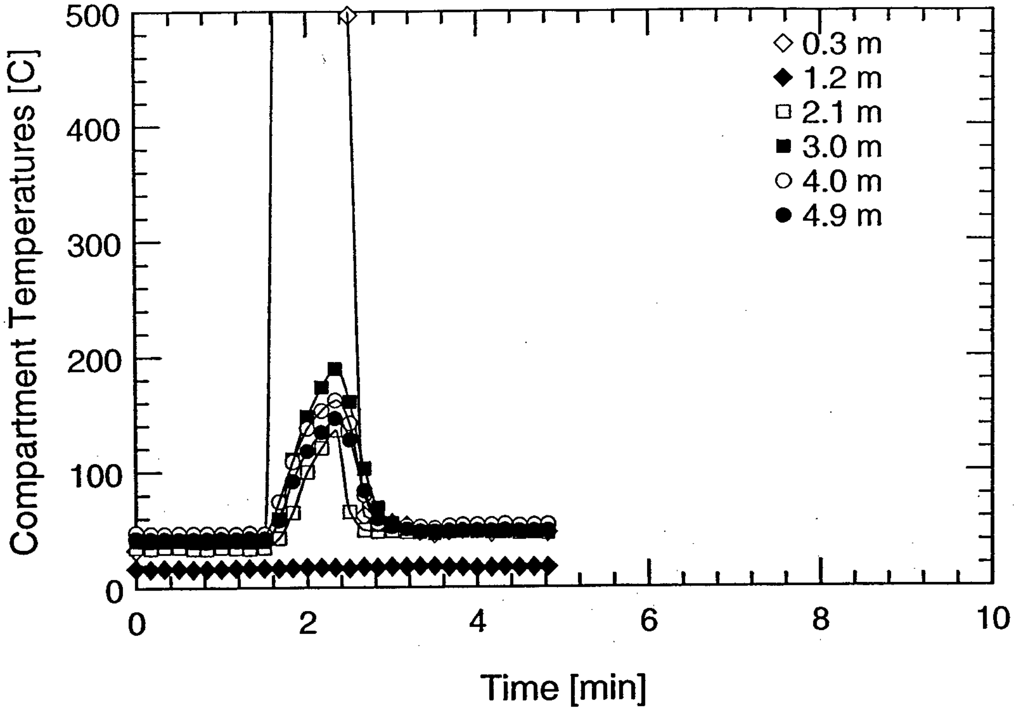


Water Mist System Flow Rate



Water Mist System Pressure

Test #60



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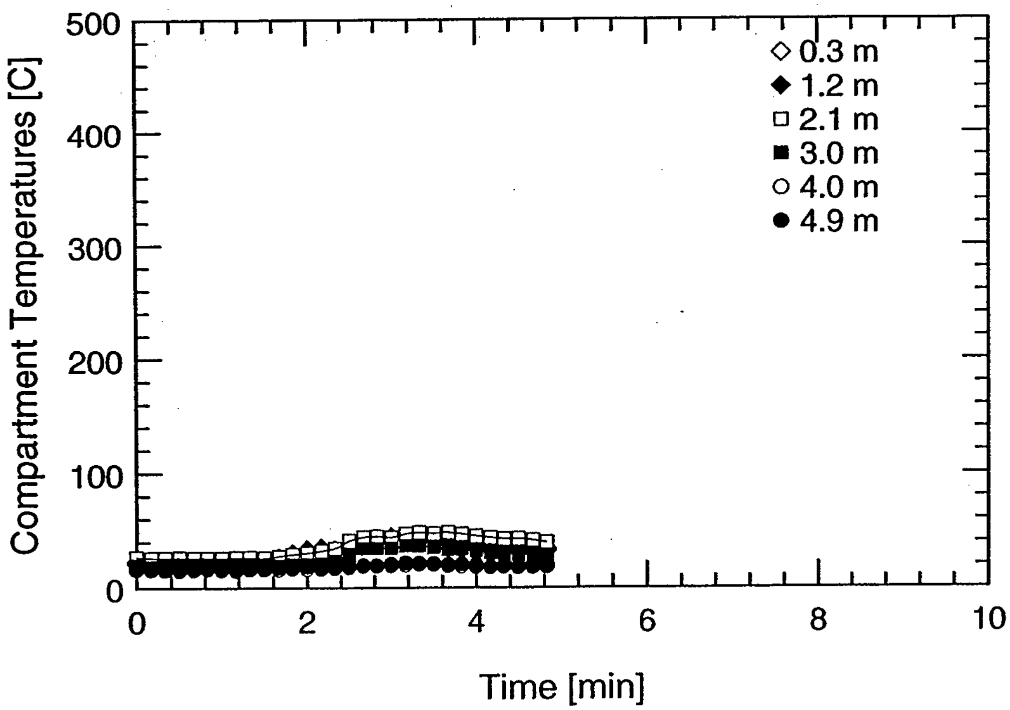

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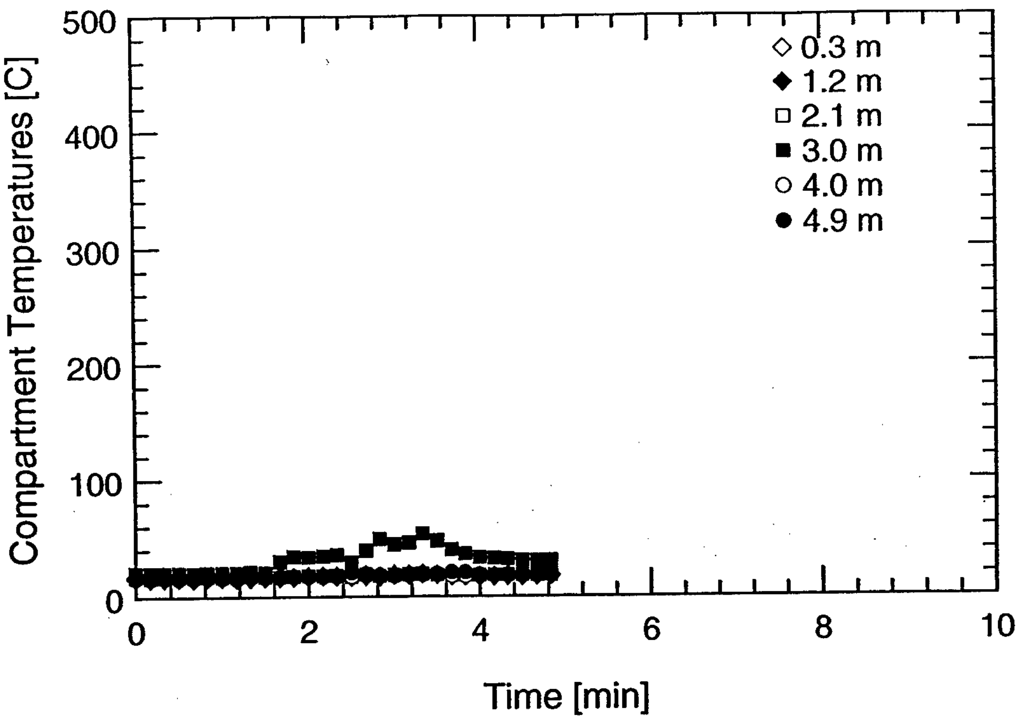

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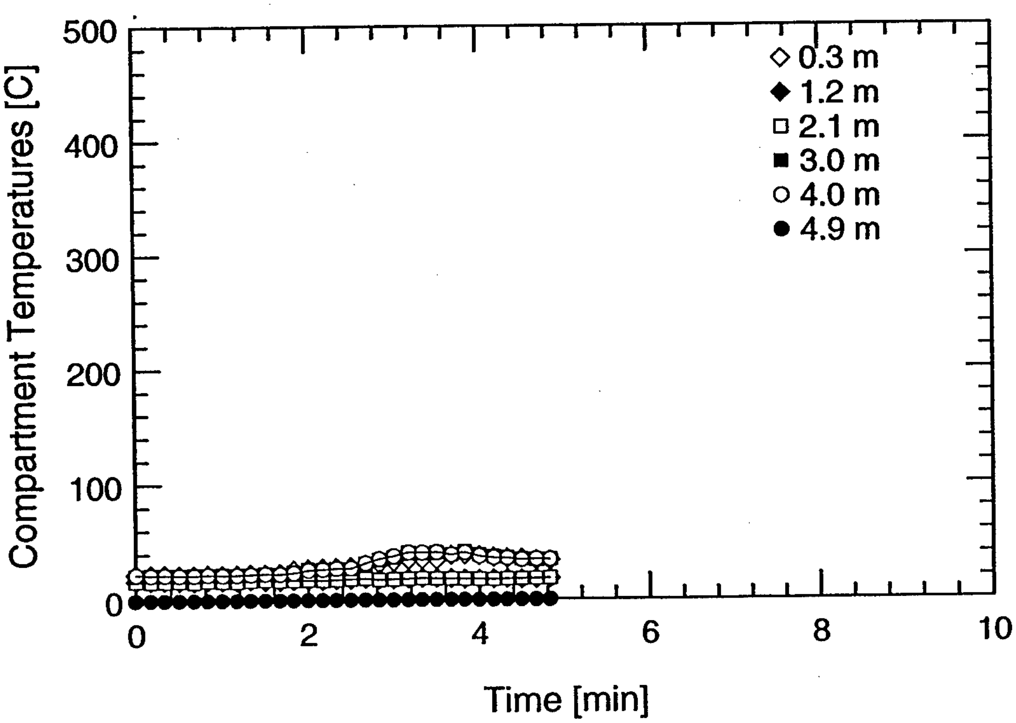

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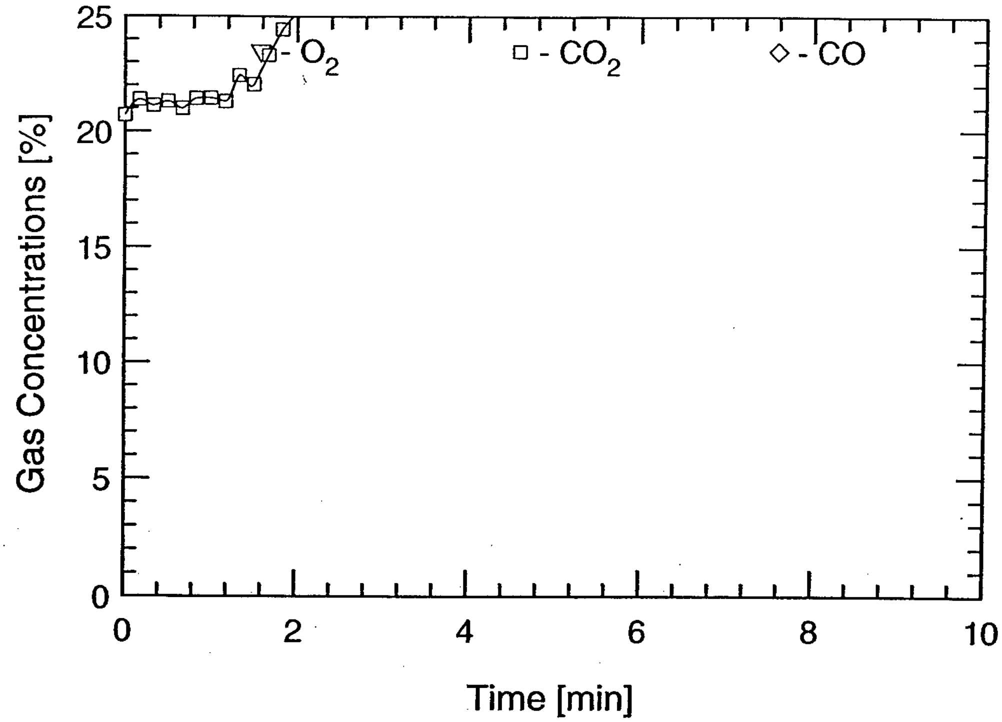

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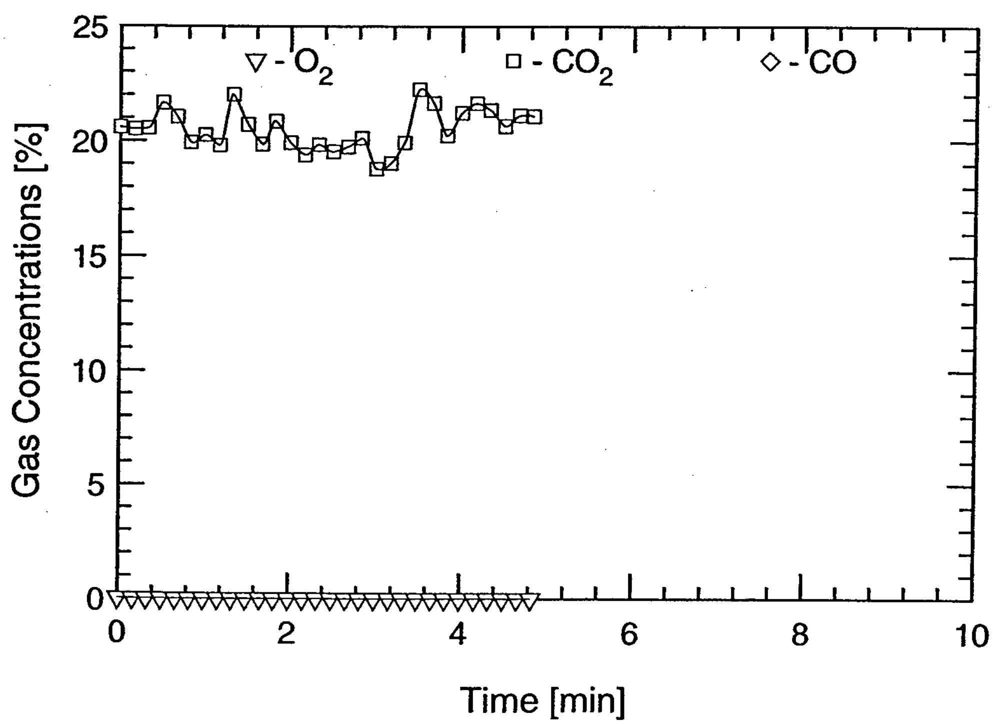

FR 22 - 4.5 m

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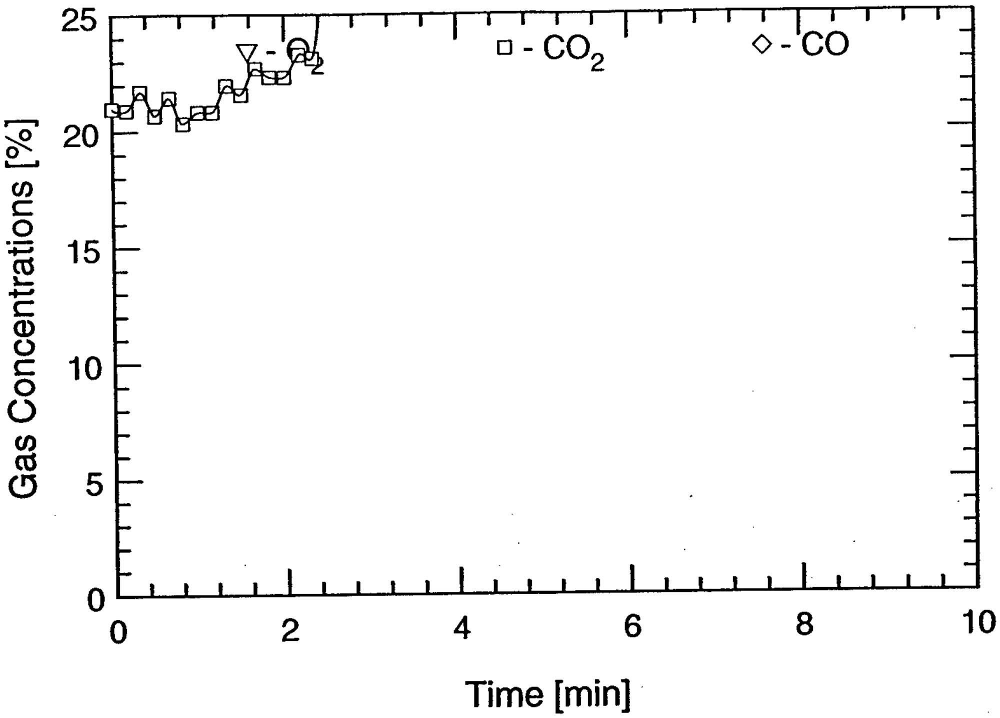

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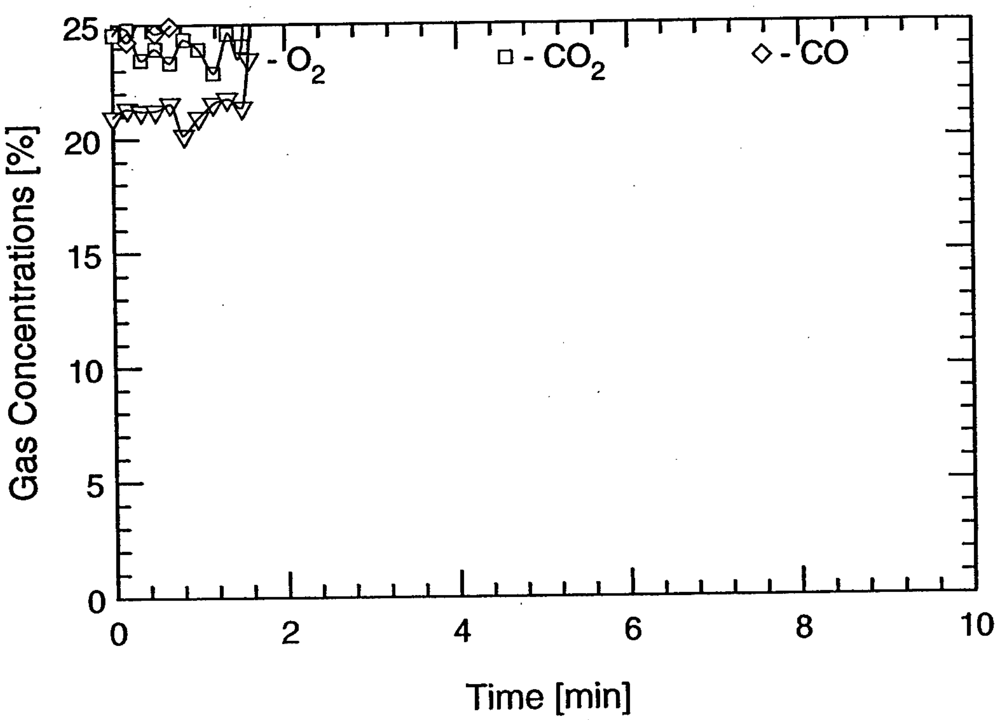

FR 36 - 4.5 m

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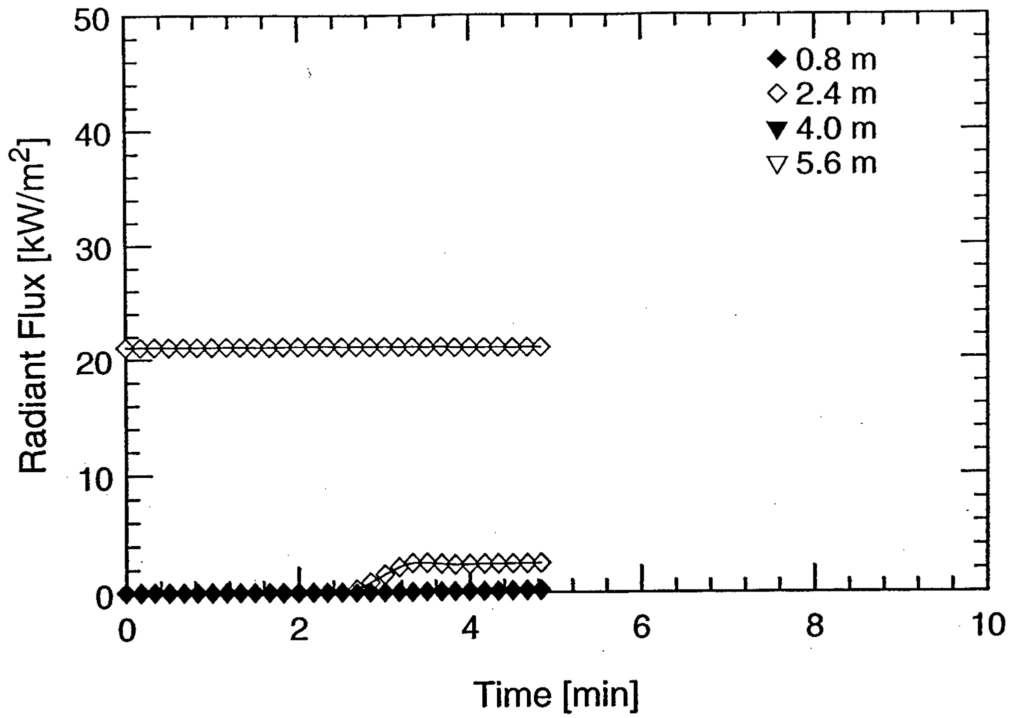

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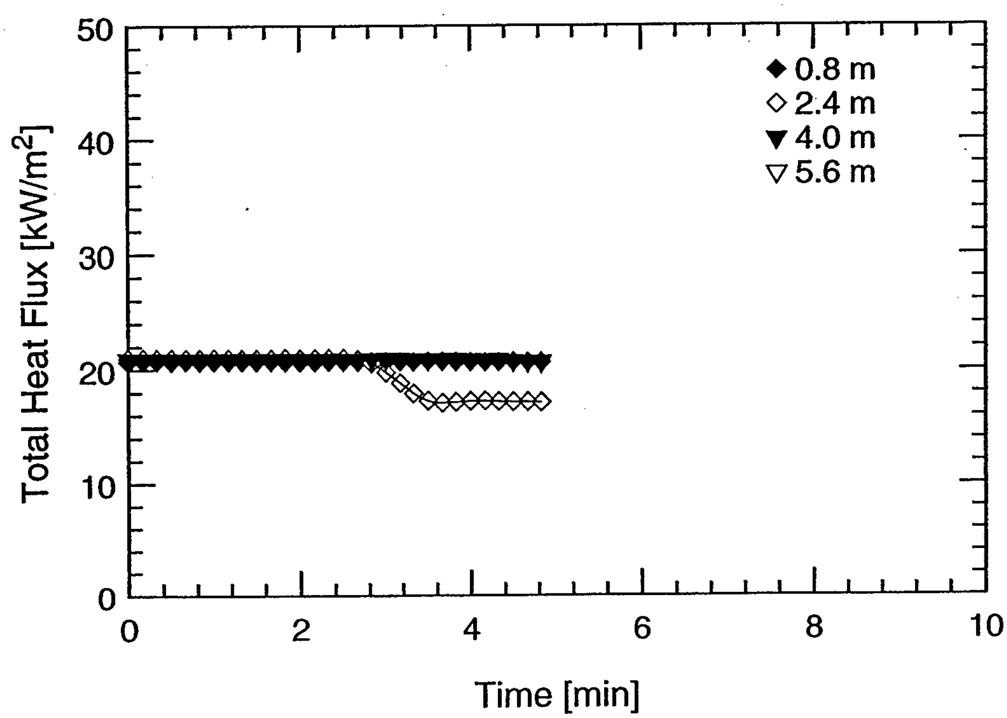

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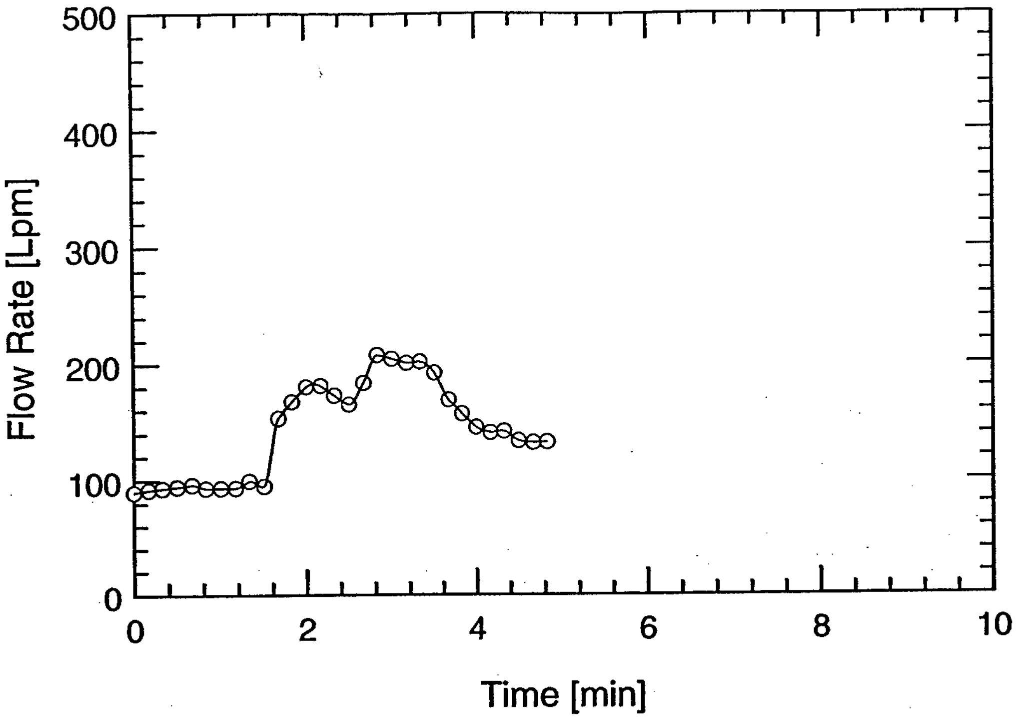
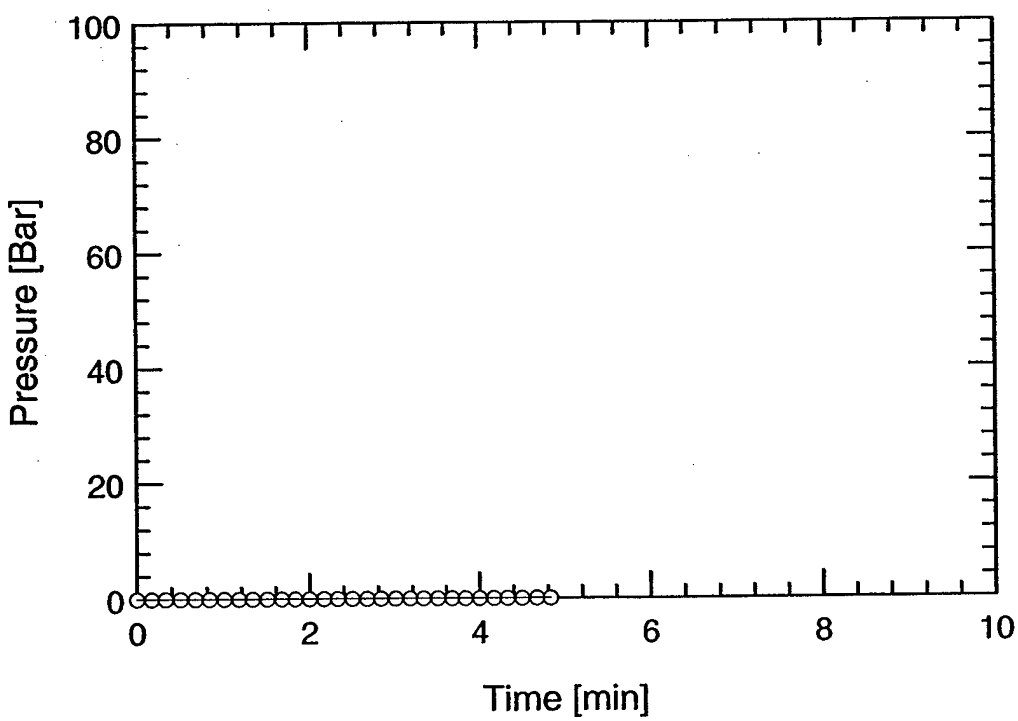
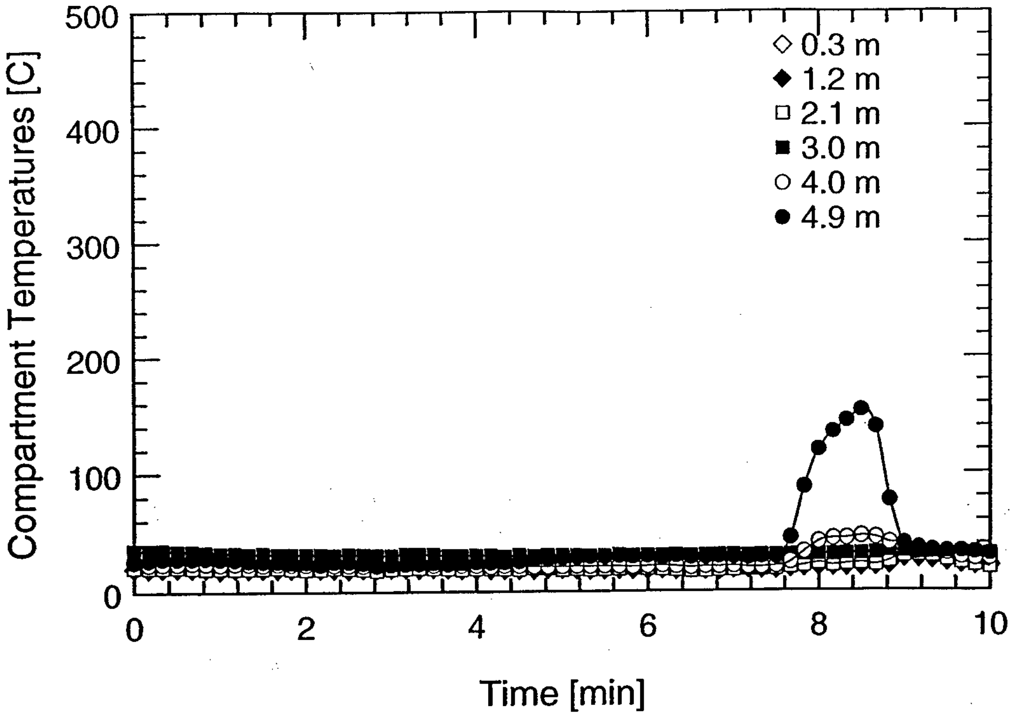


Water Mist System Flow Rate



Water Mist System Pressure

Test #61



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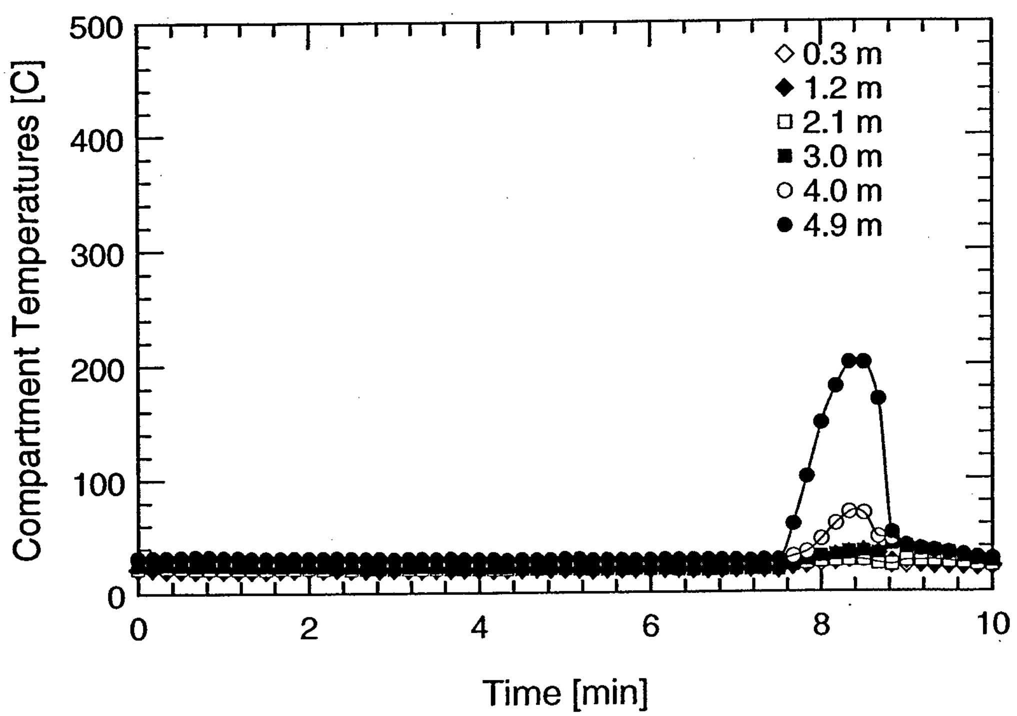

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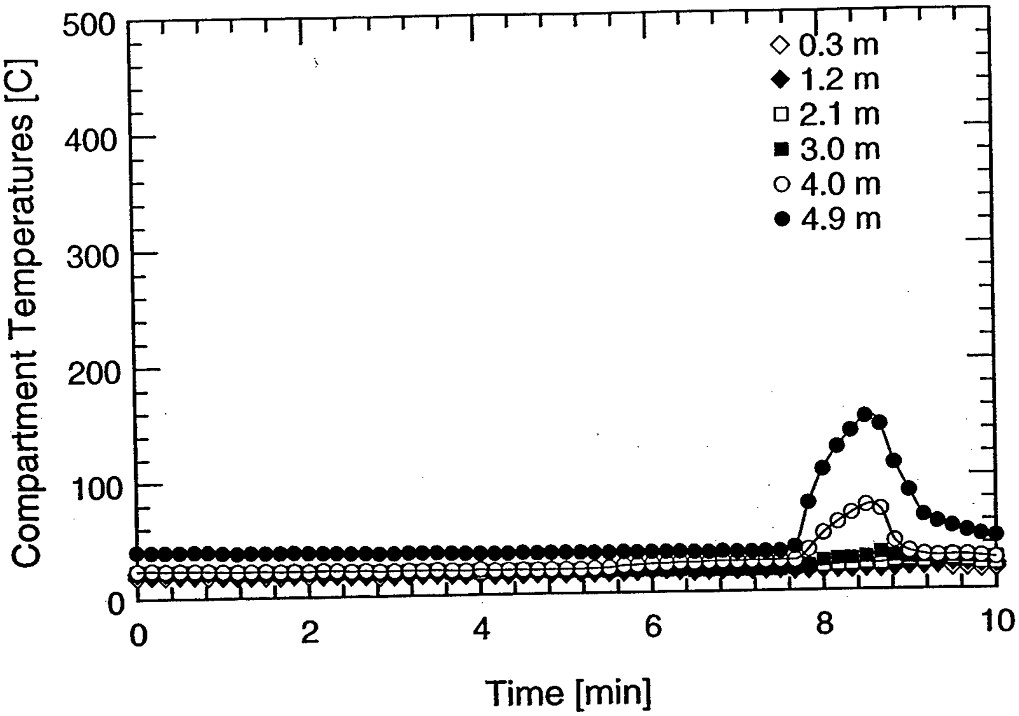

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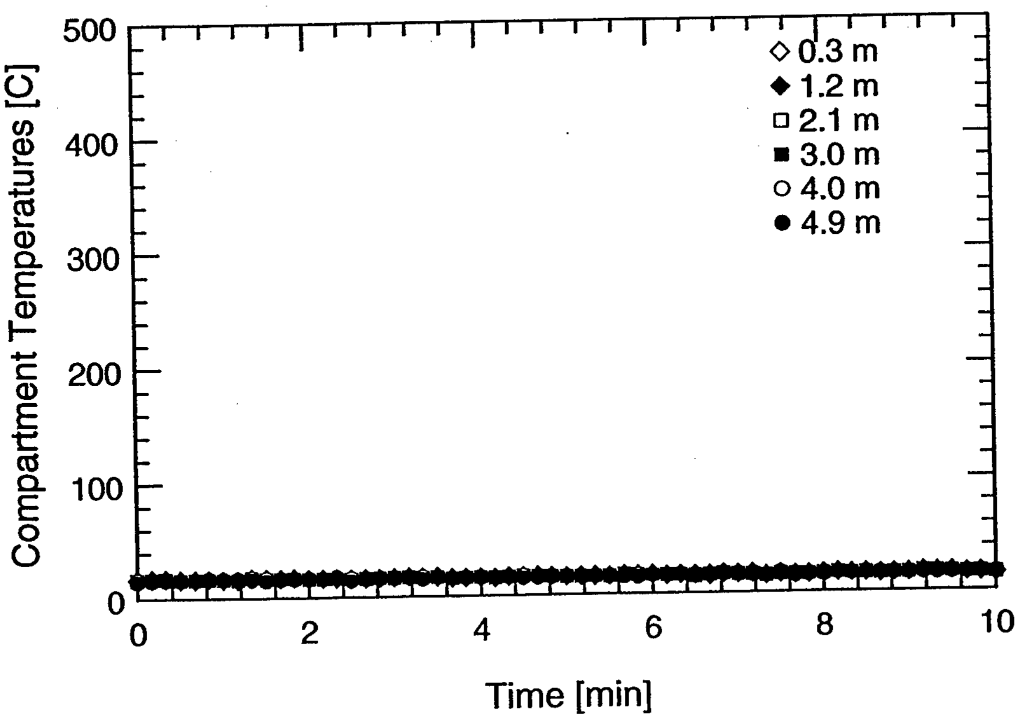

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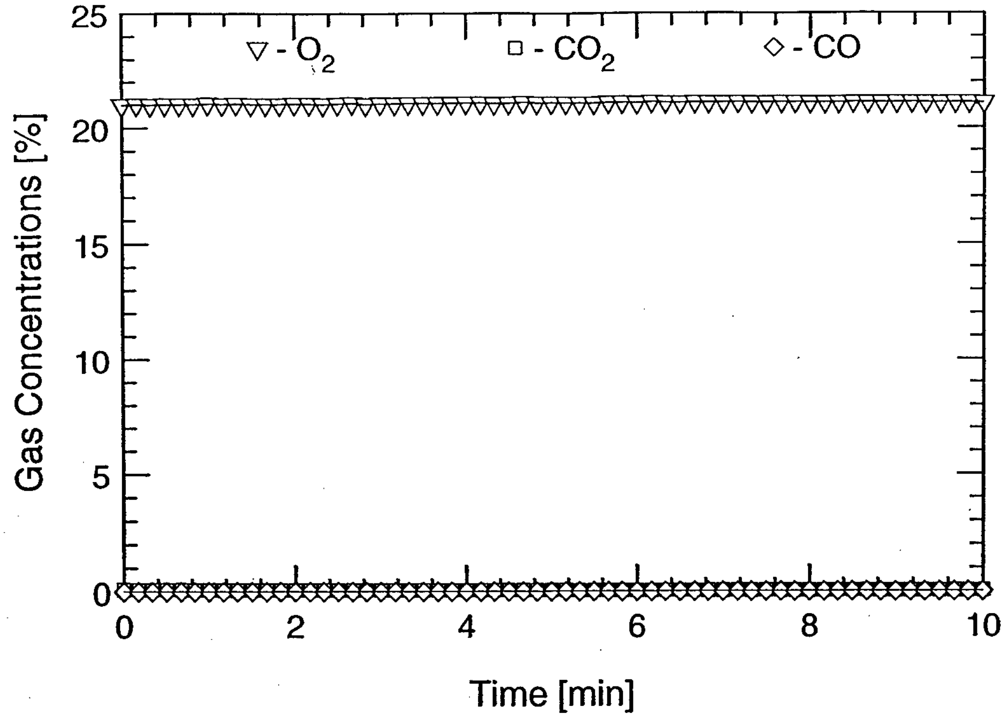
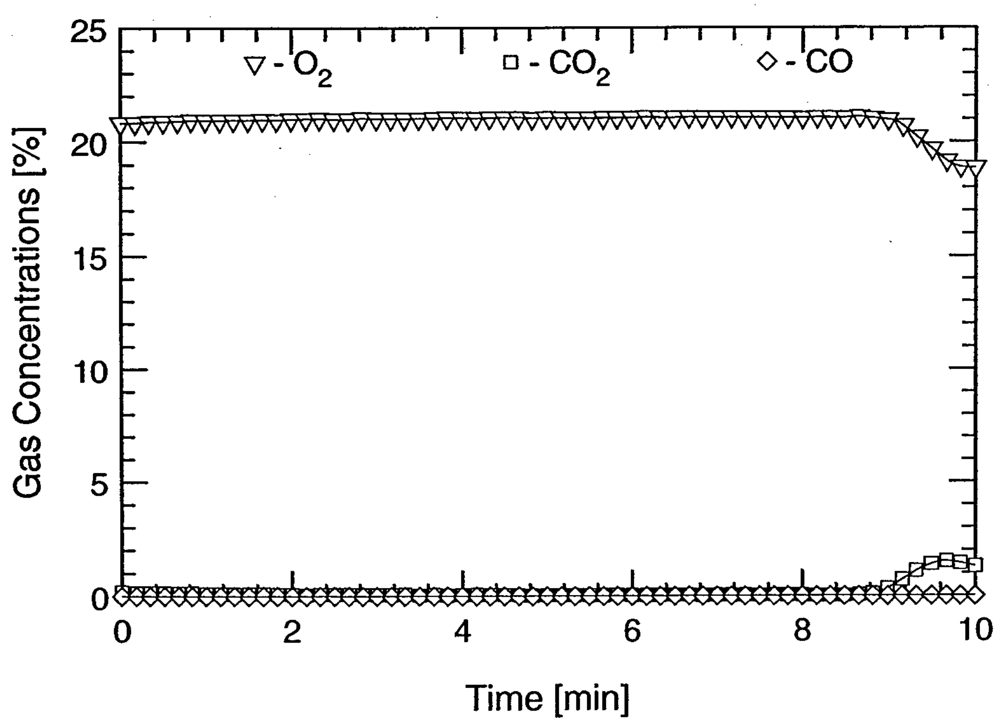


FR 22 - 0.5 m



FR 22 - 4.5 m

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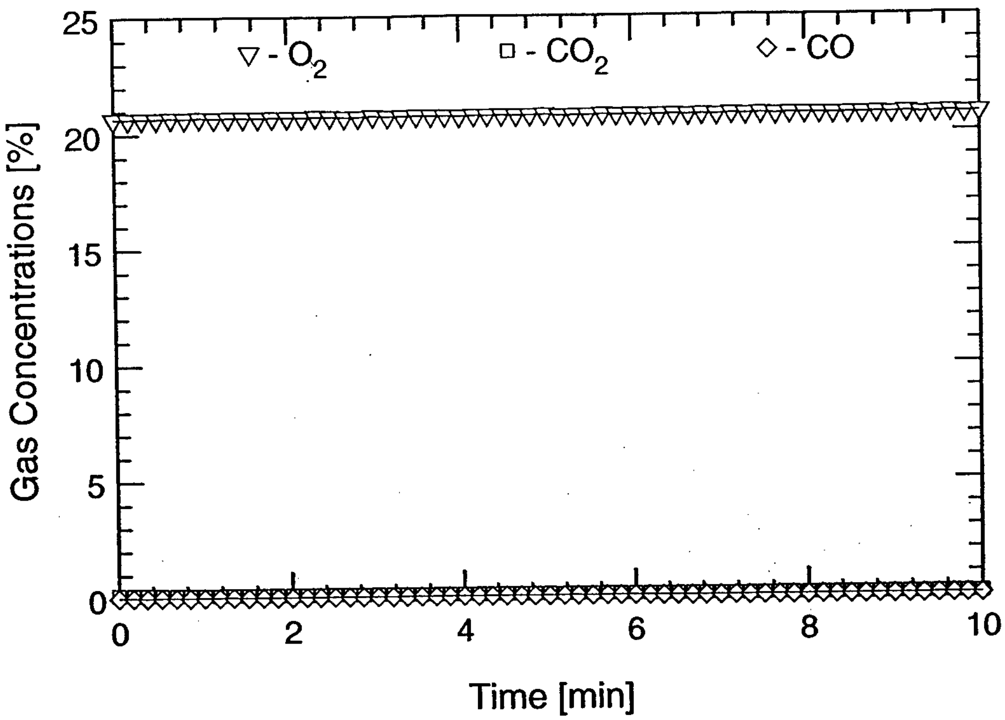

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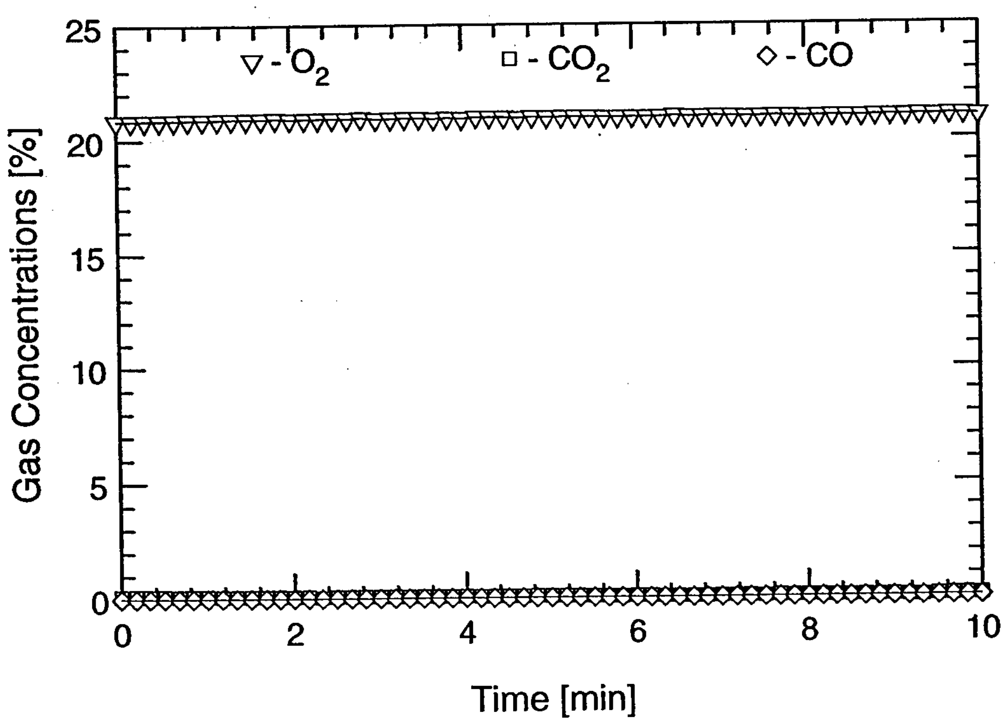

FR 36 - 4.5 m

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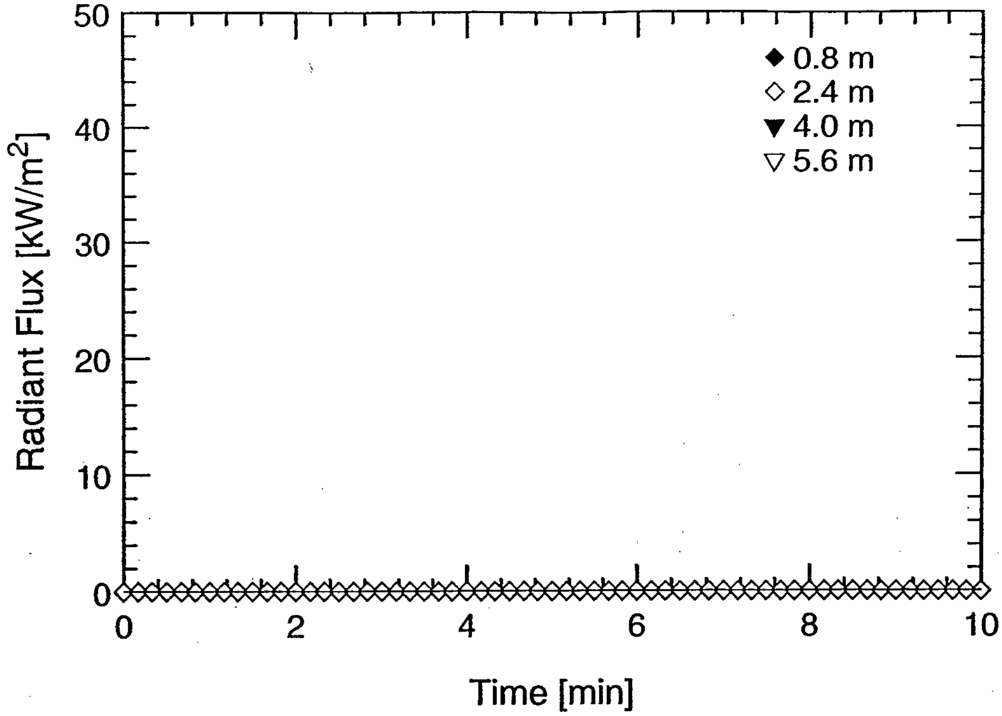

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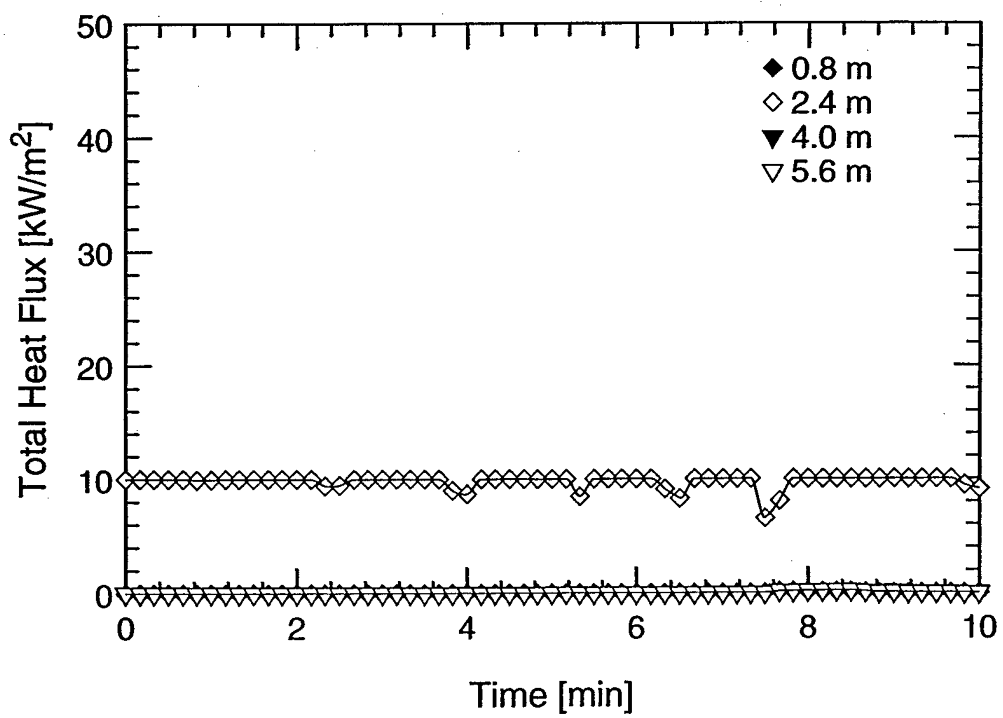

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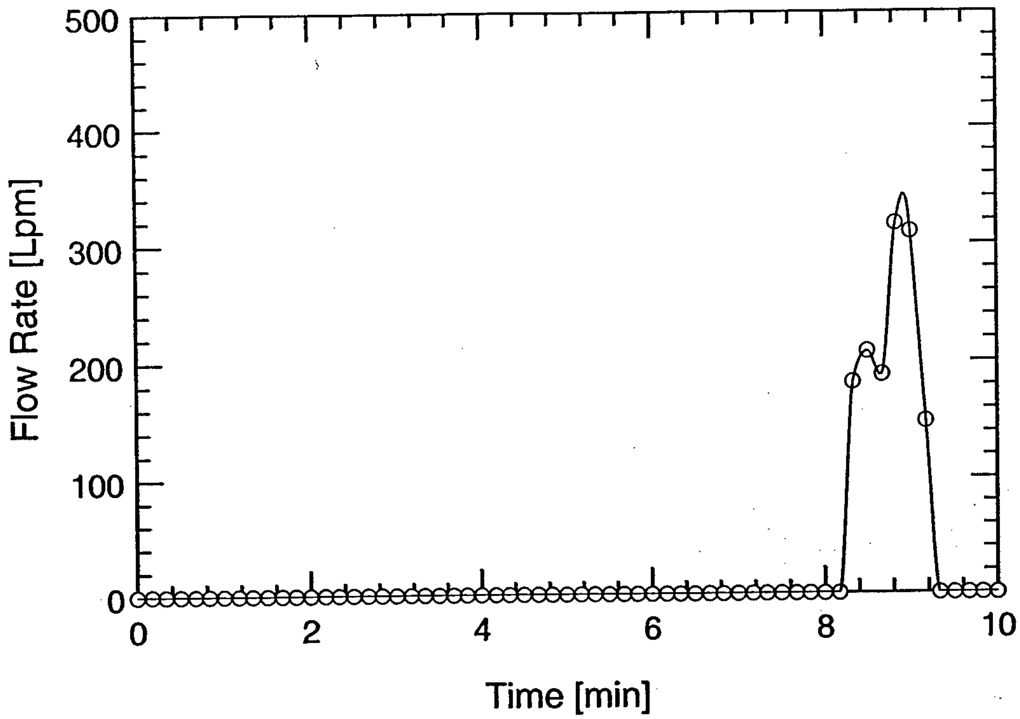
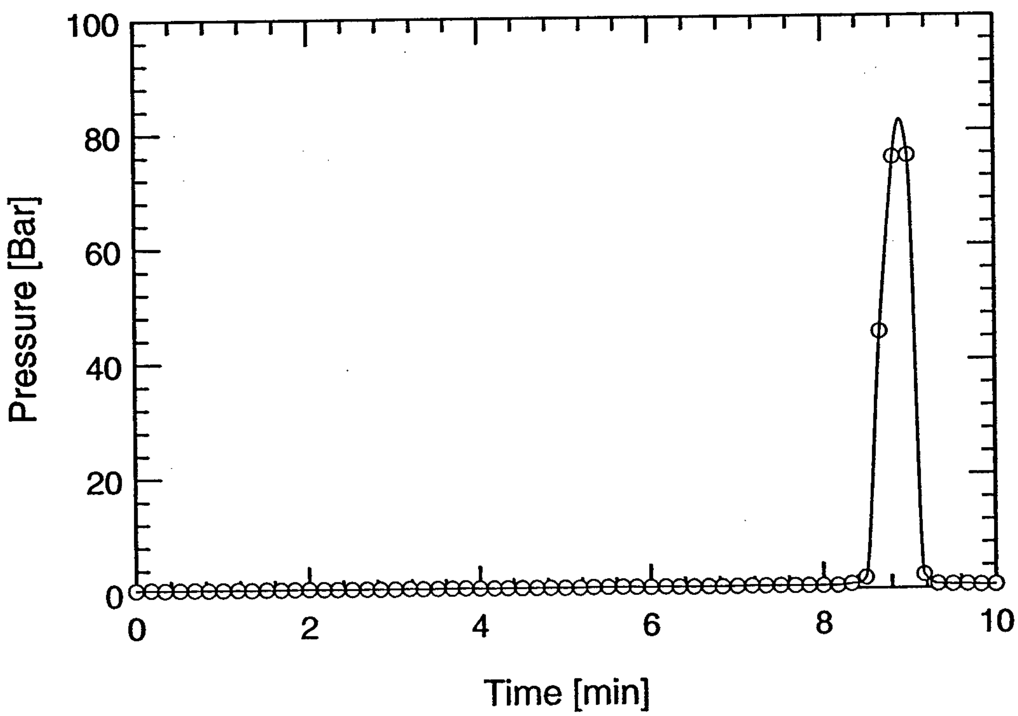
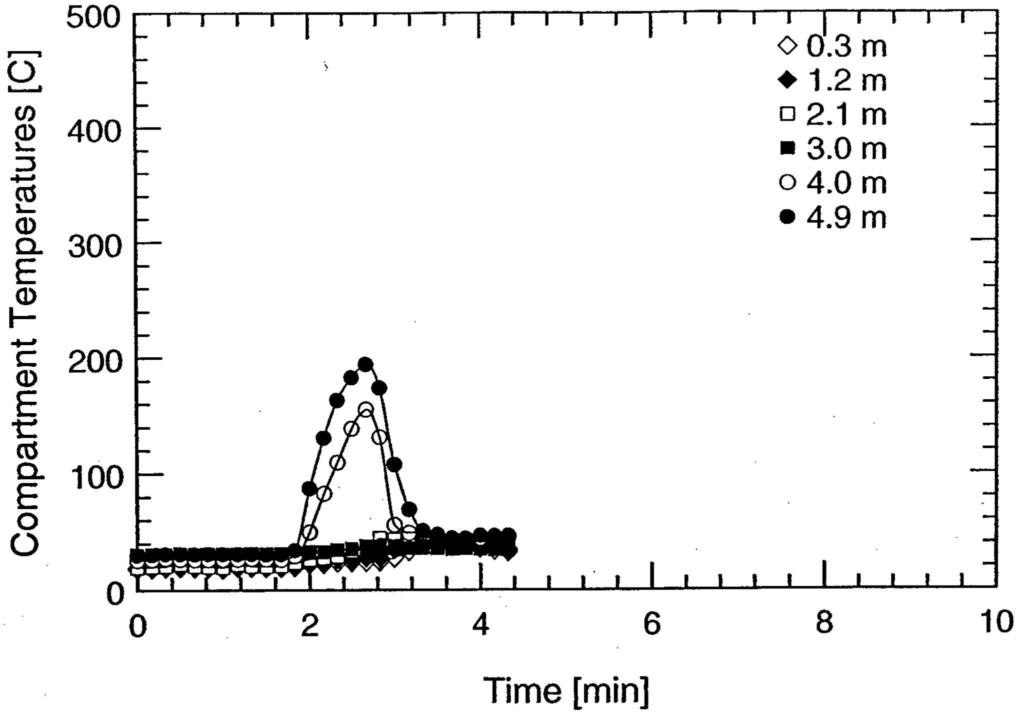


Water Mist System Flow Rate



Water Mist System Pressure

Test #62



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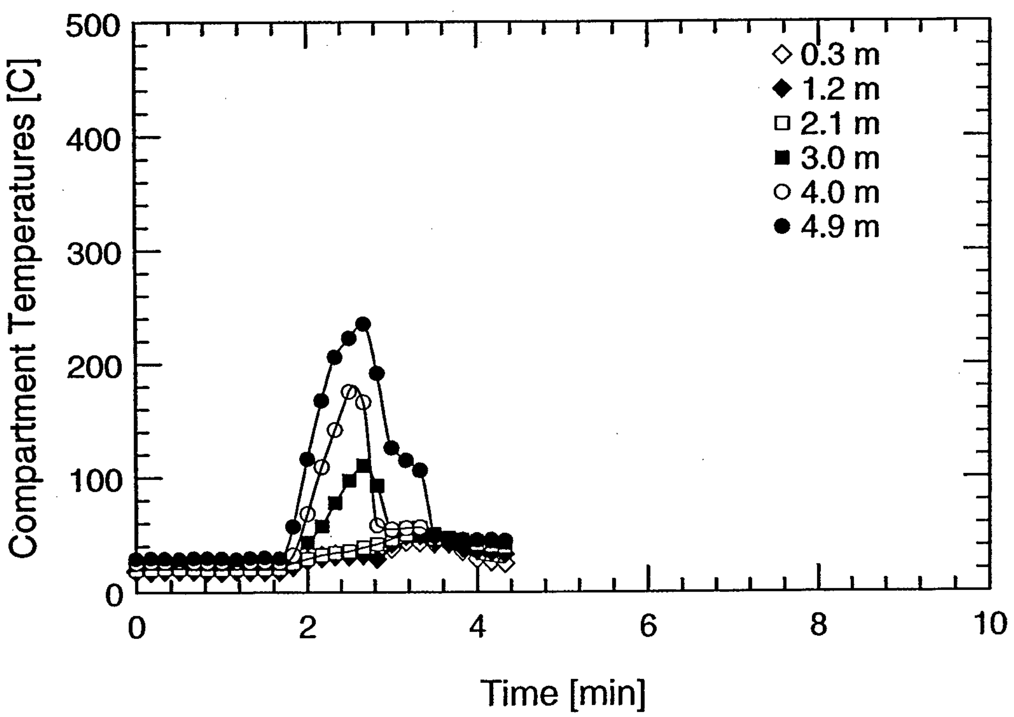

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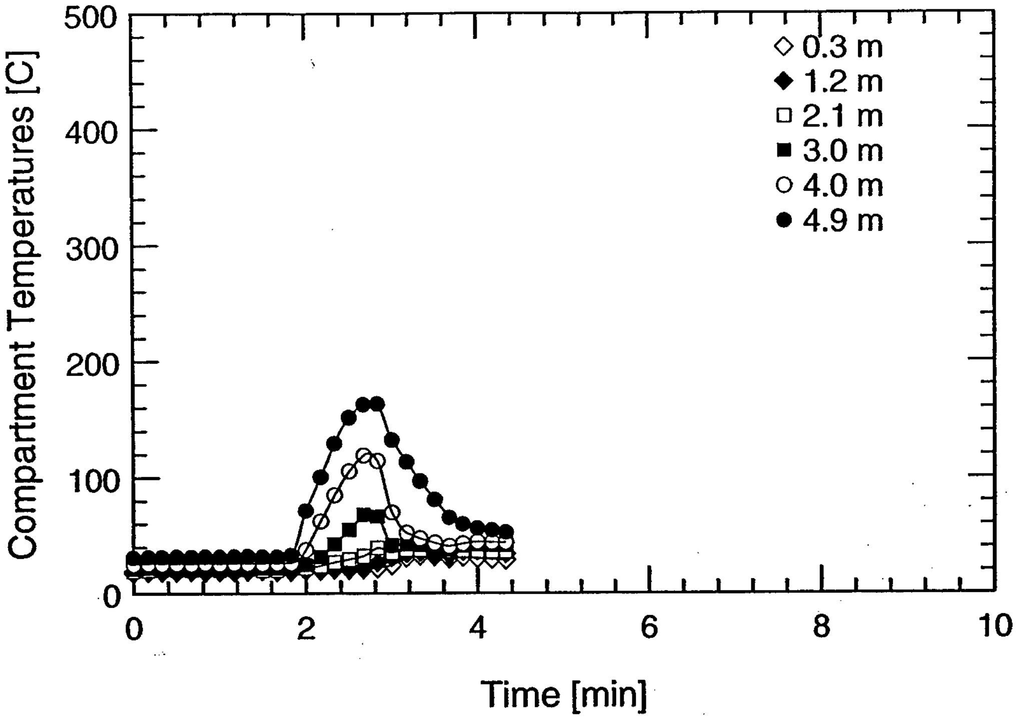

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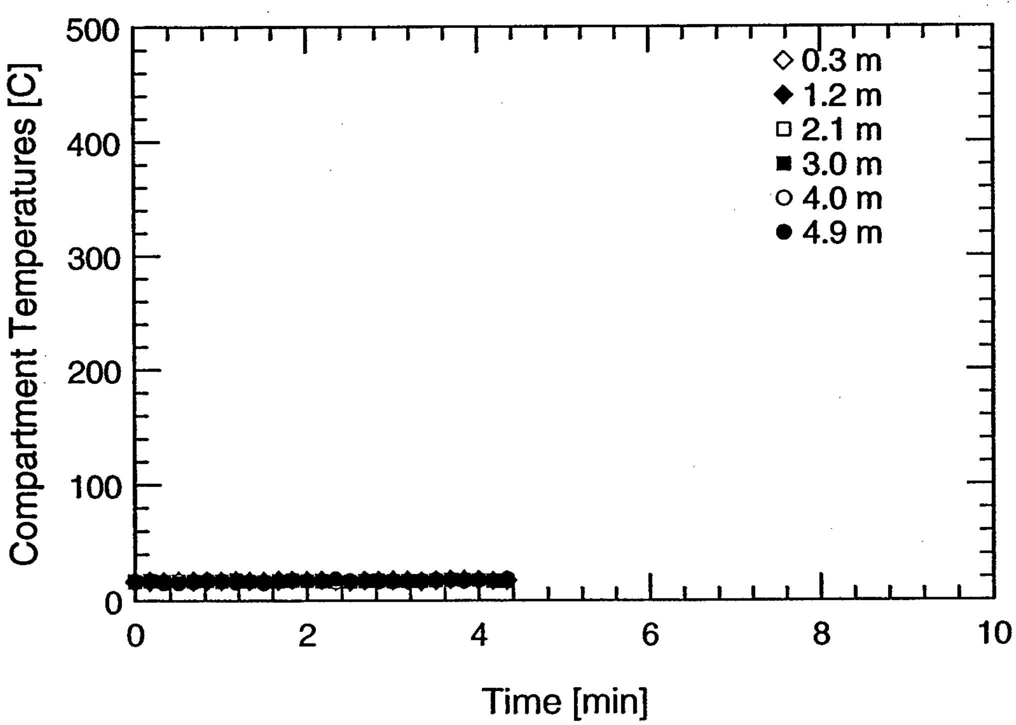

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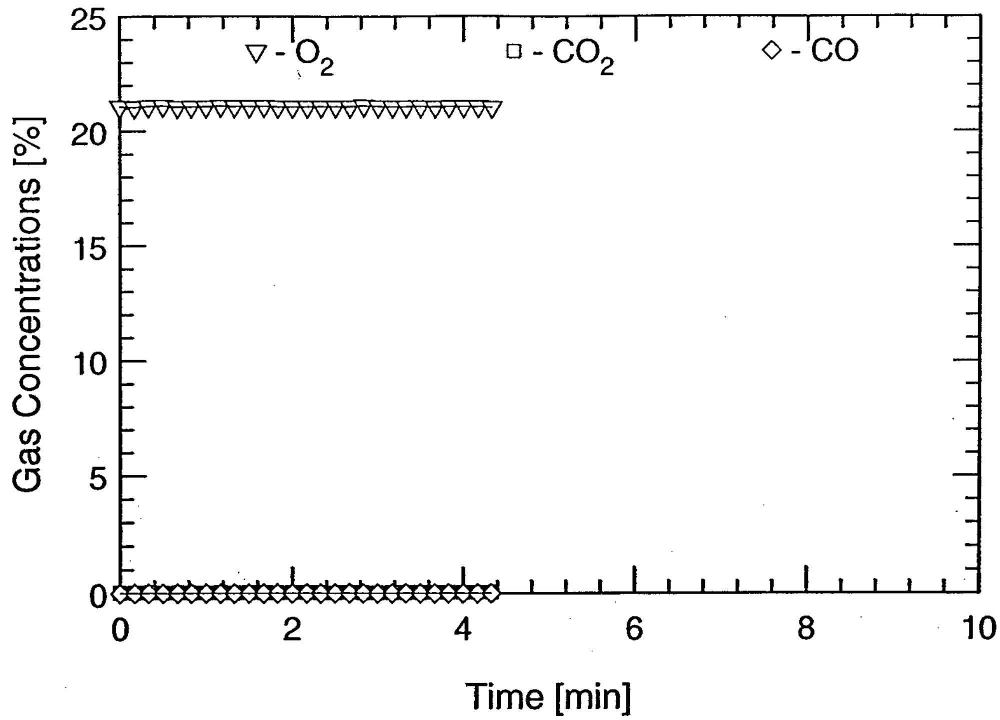
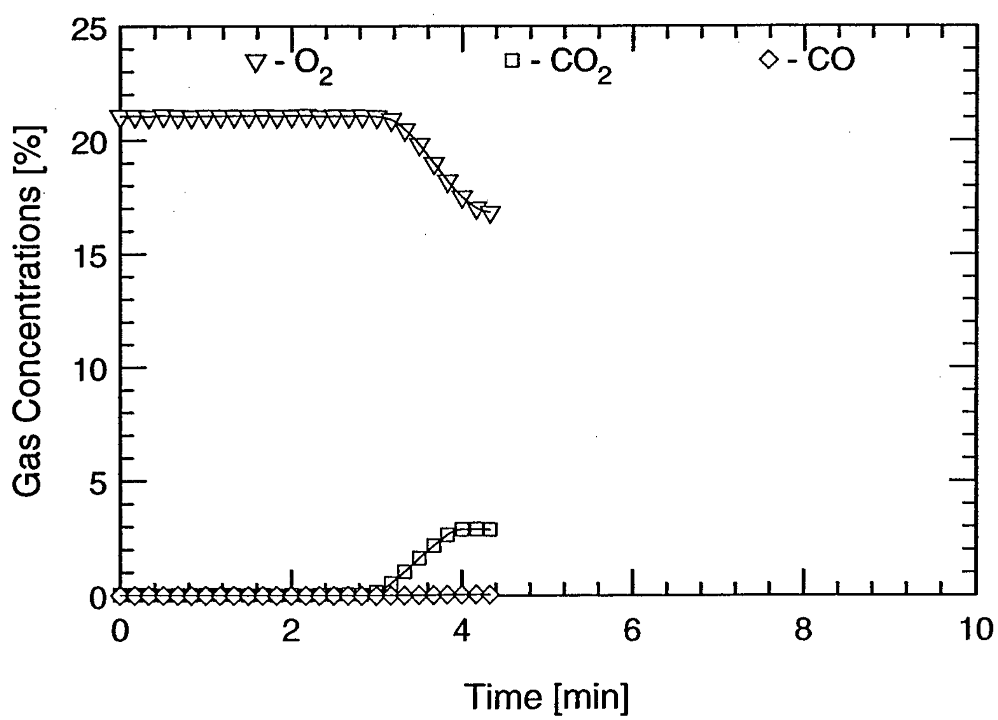


FR 22 - 0.5 m



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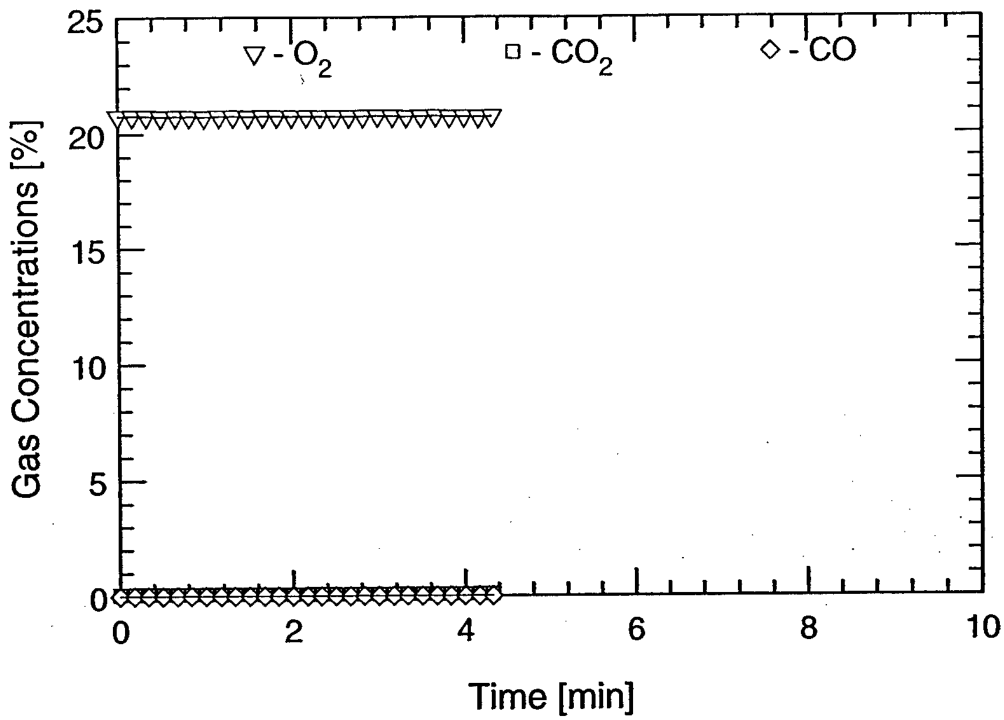

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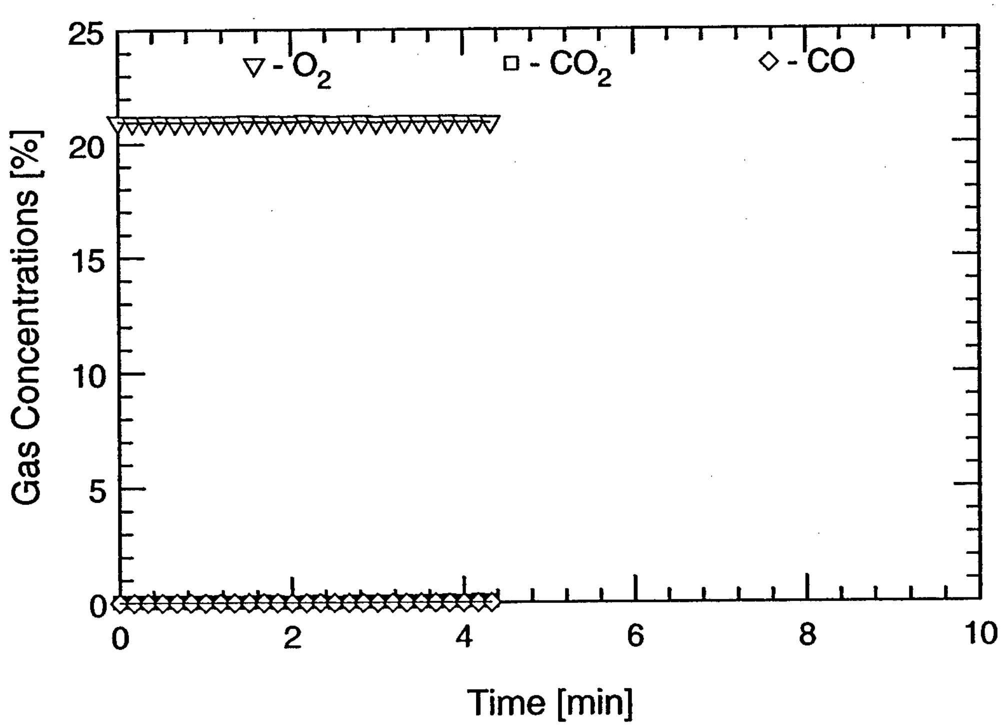

FR 36 - 4.5 m

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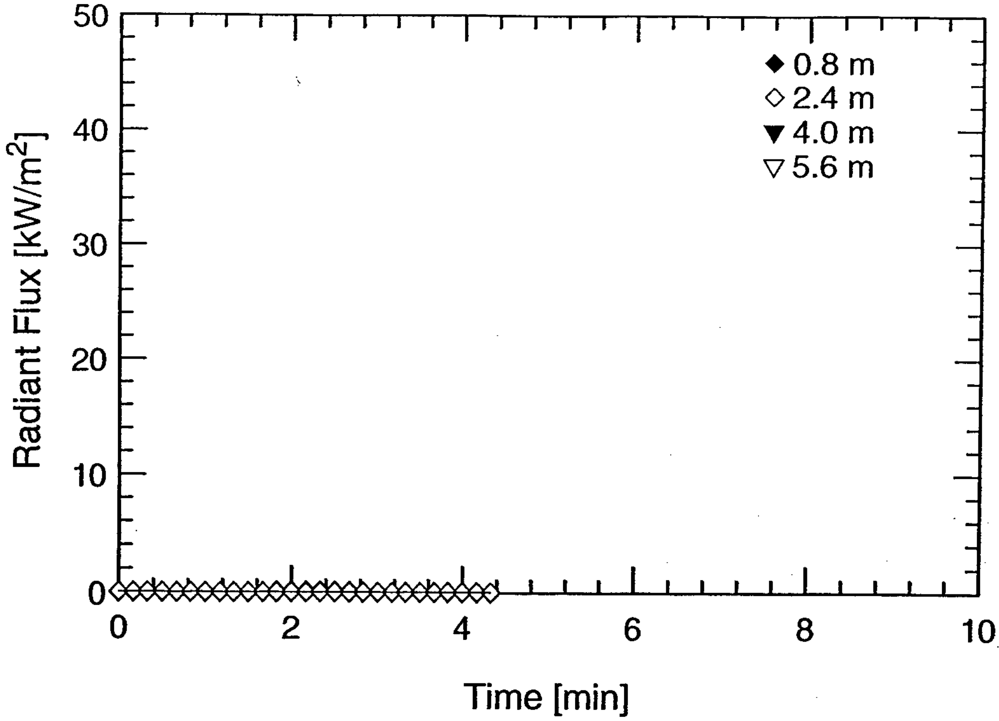

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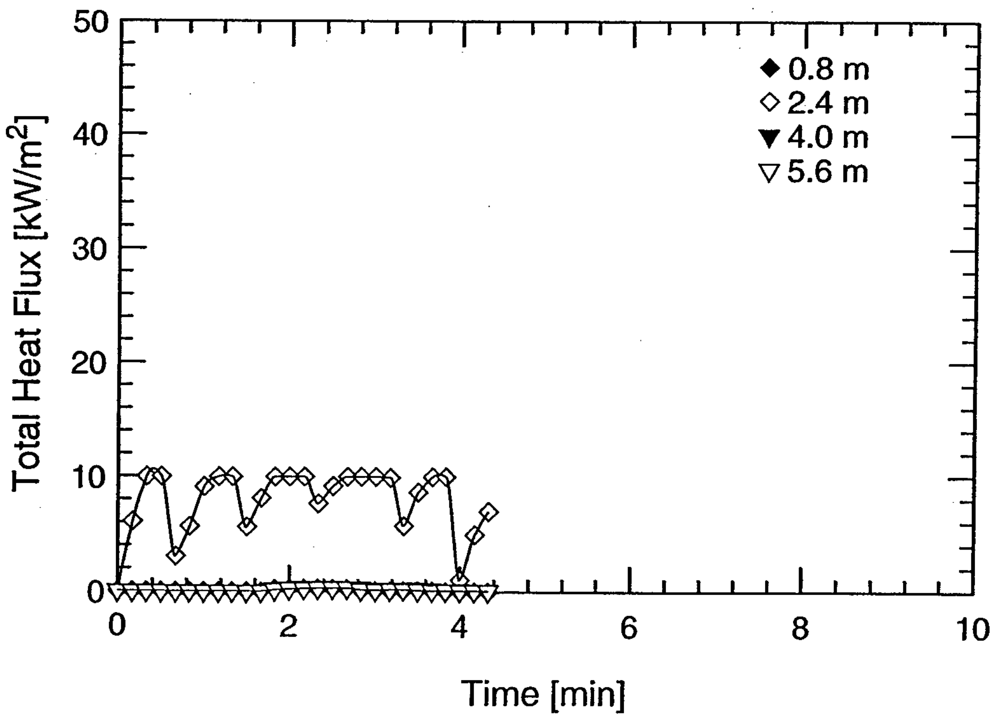

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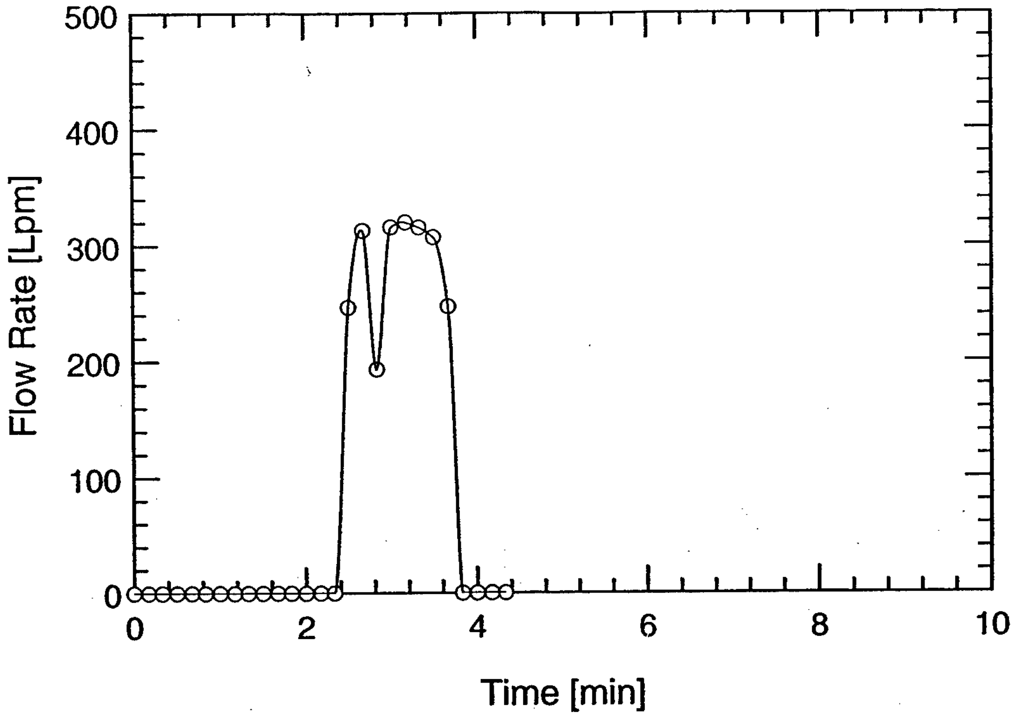
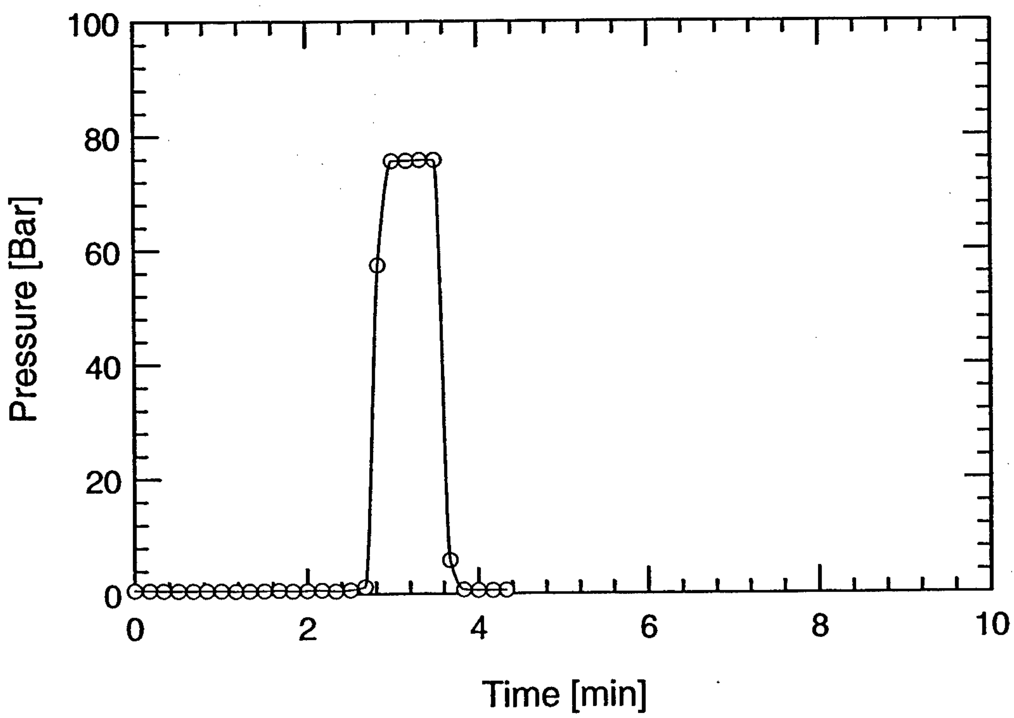
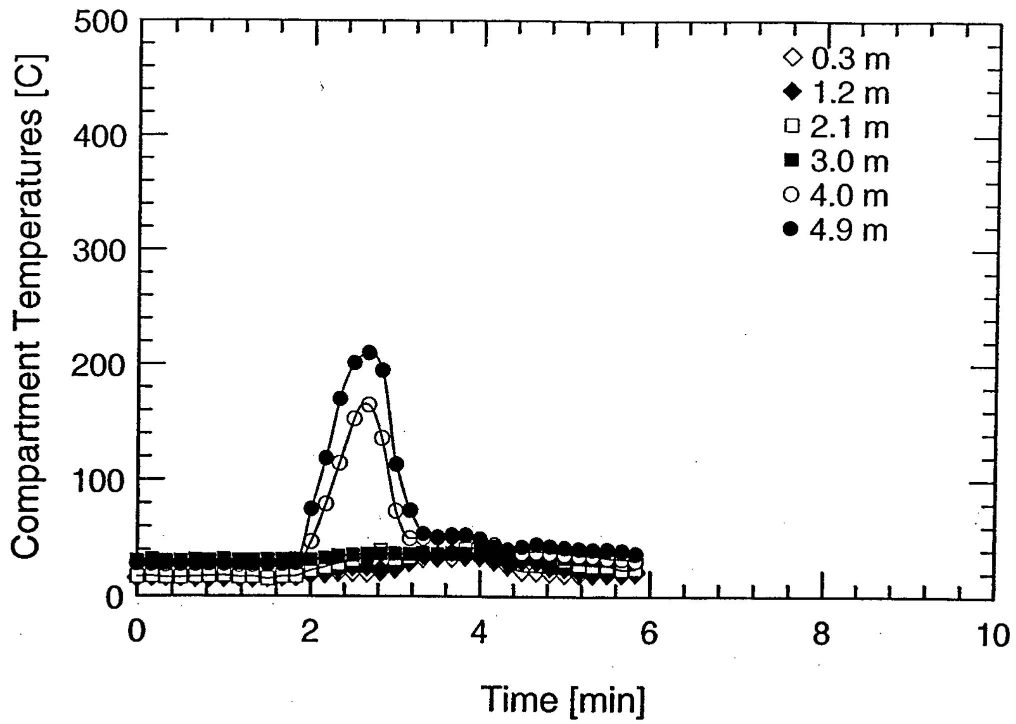


Water Mist System Flow Rate



Water Mist System Pressure

Test #63



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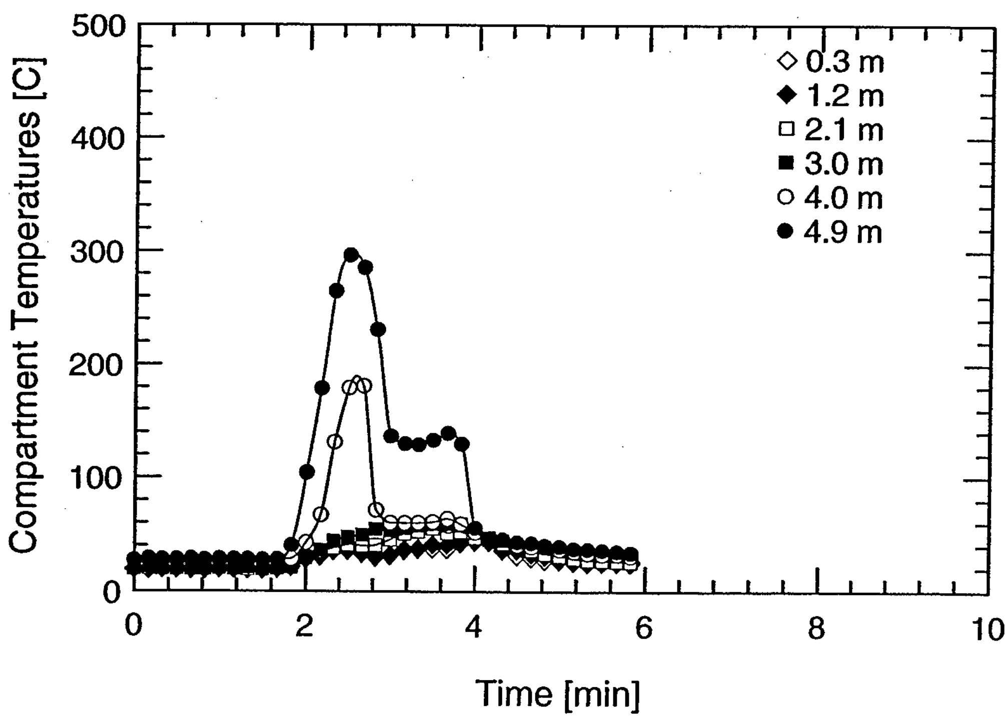

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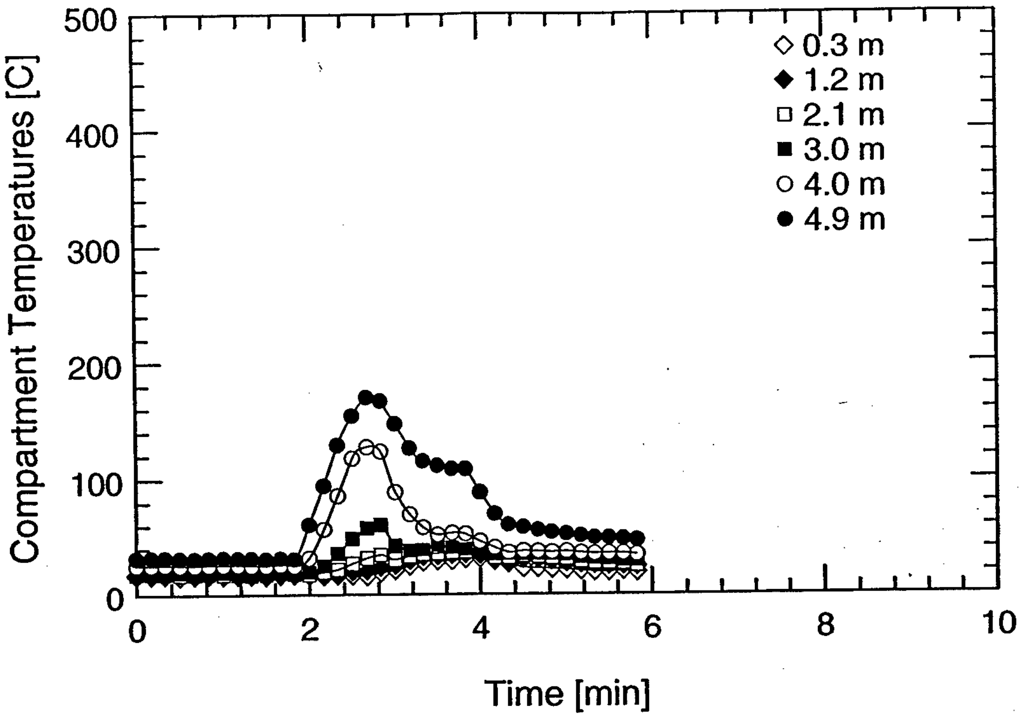

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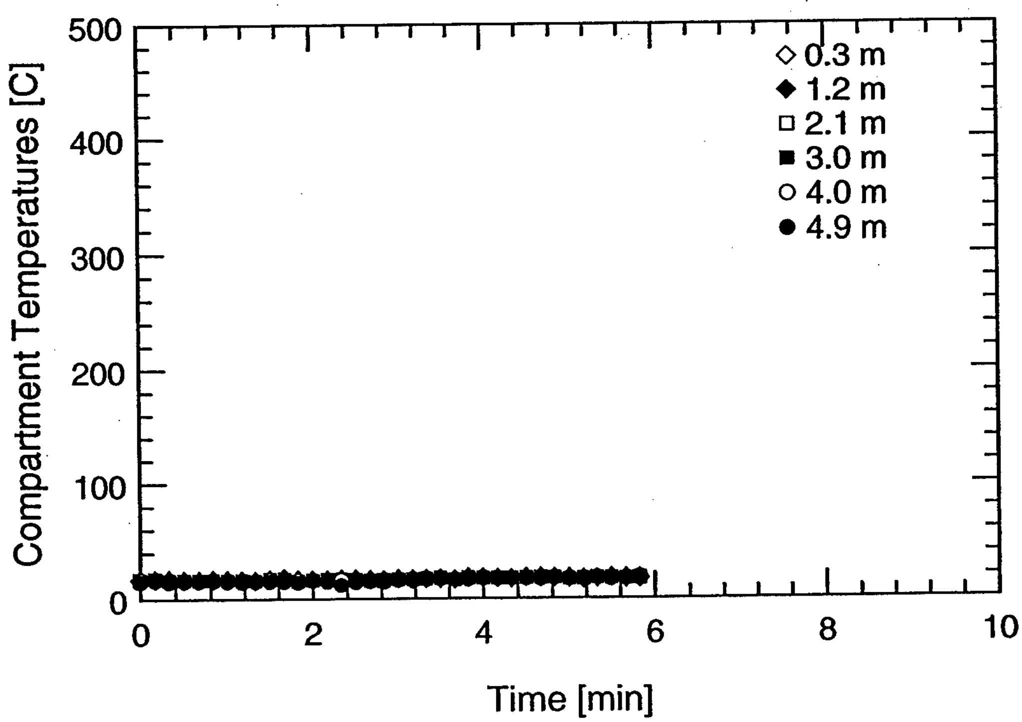

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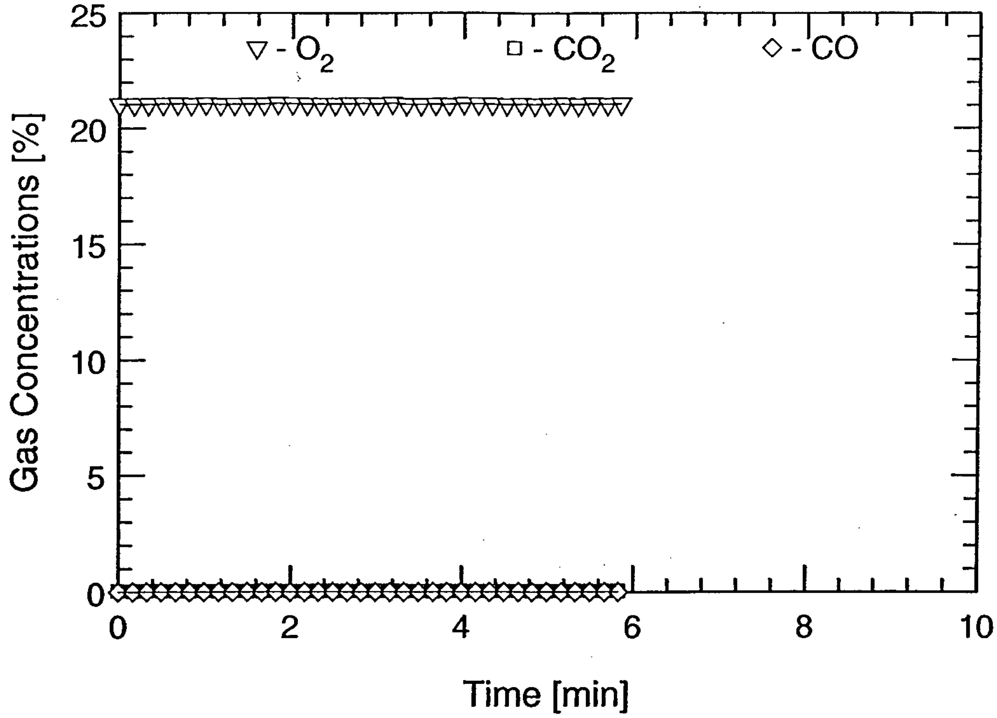

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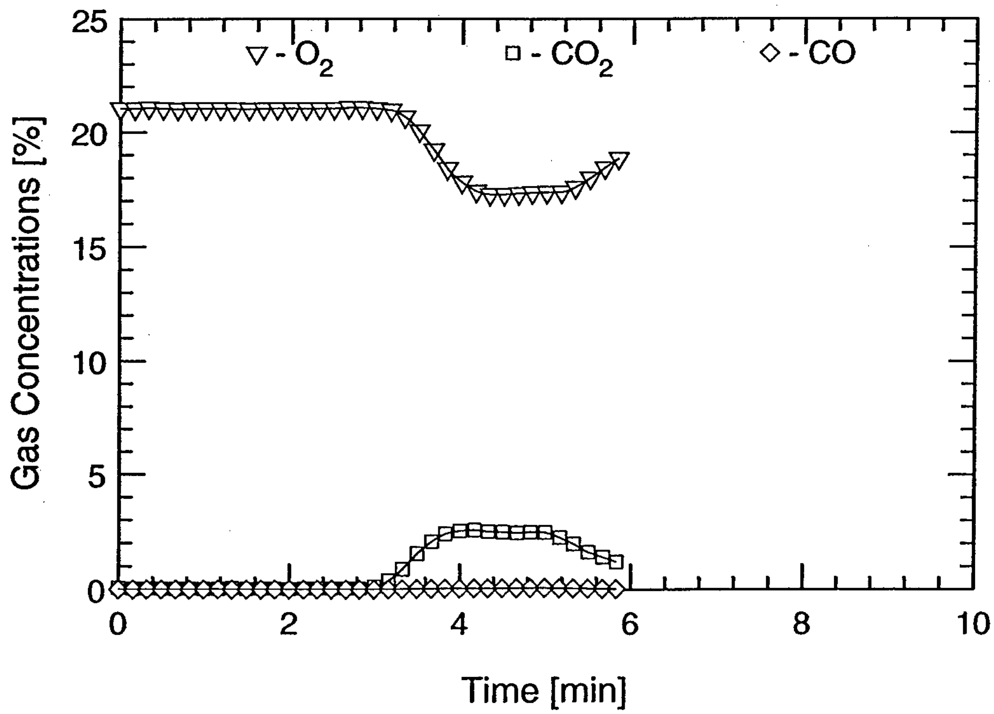

FR 22 - 4.5 m

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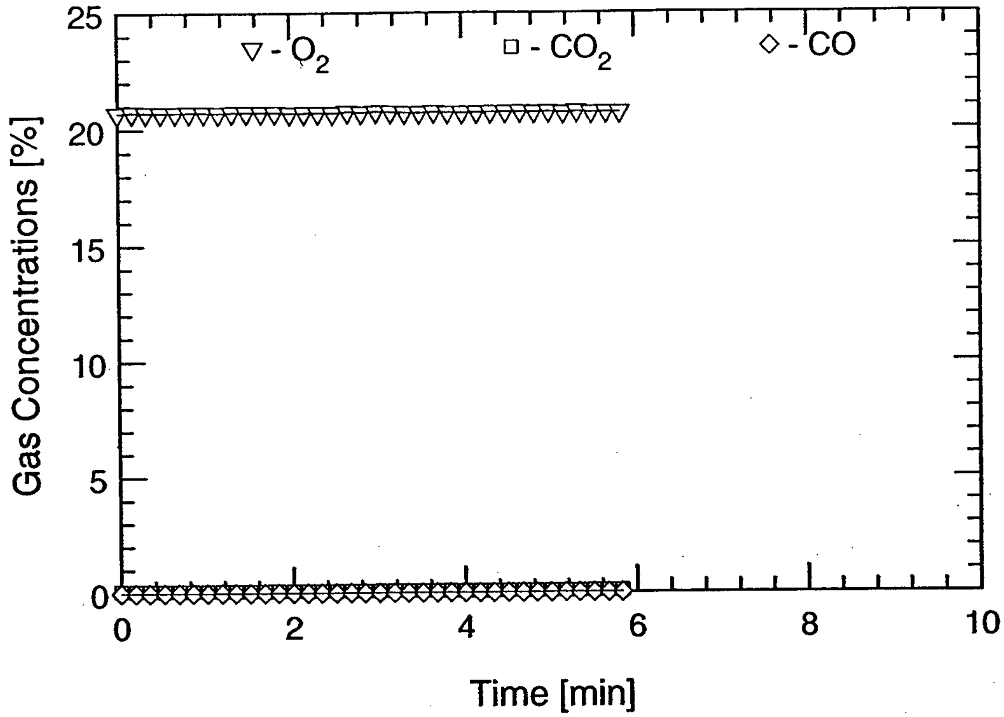
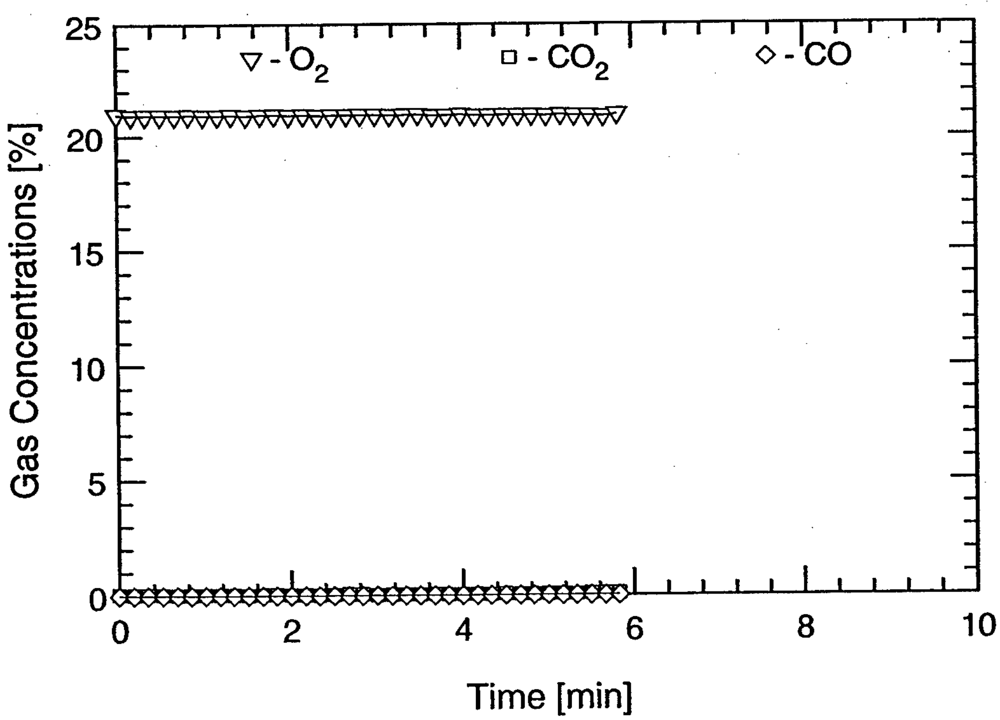


FR 36 - 0.5 m



FR 36 - 4.5 m

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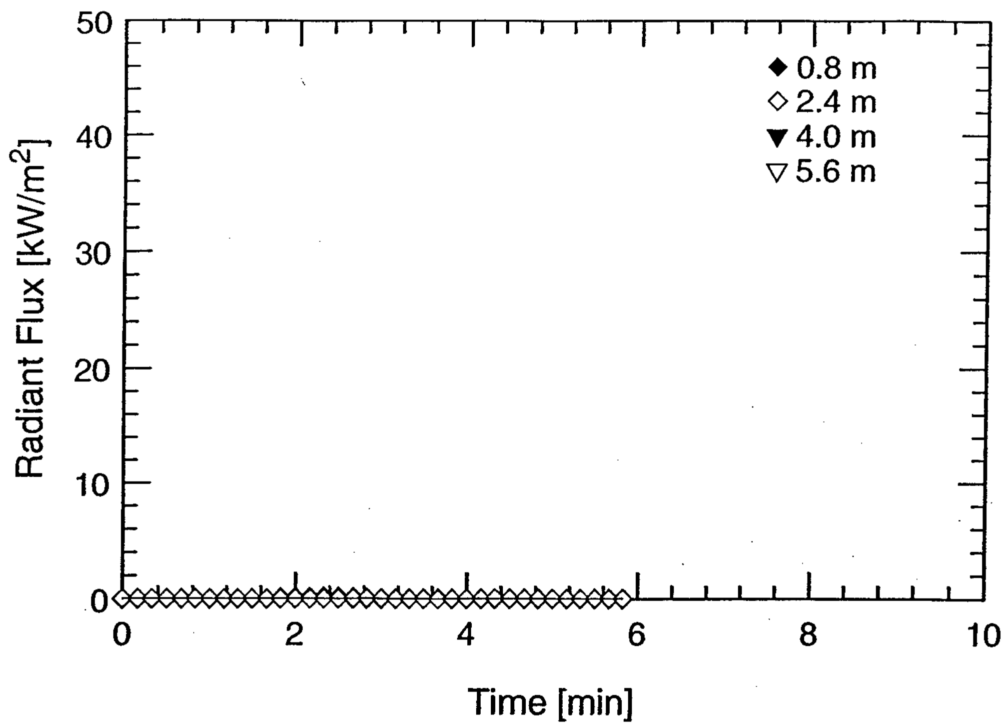

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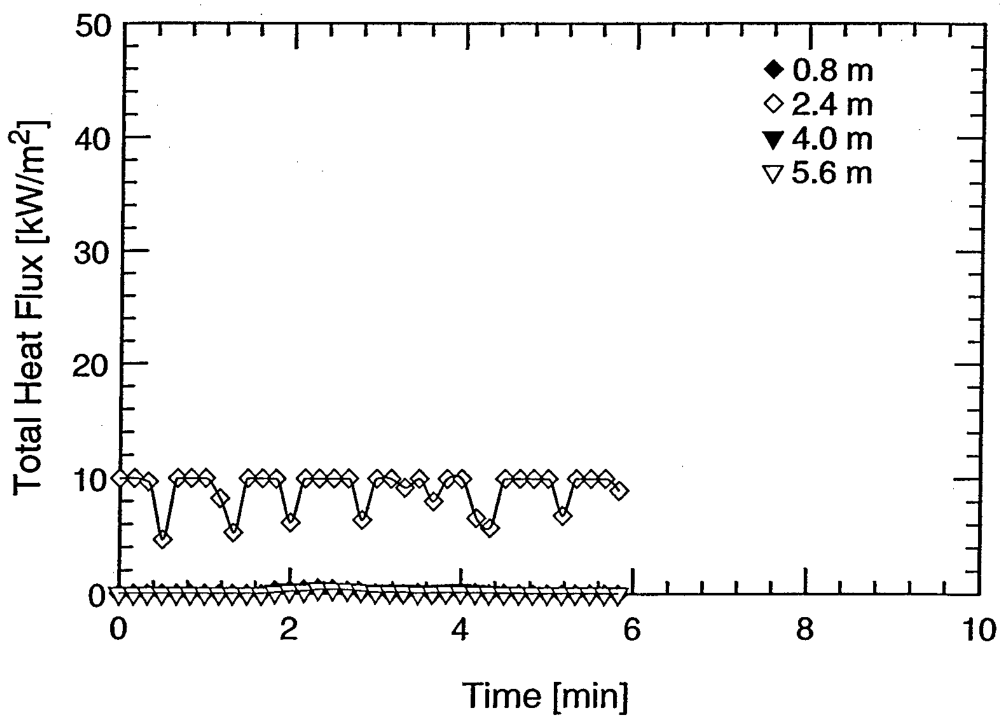

FR 22

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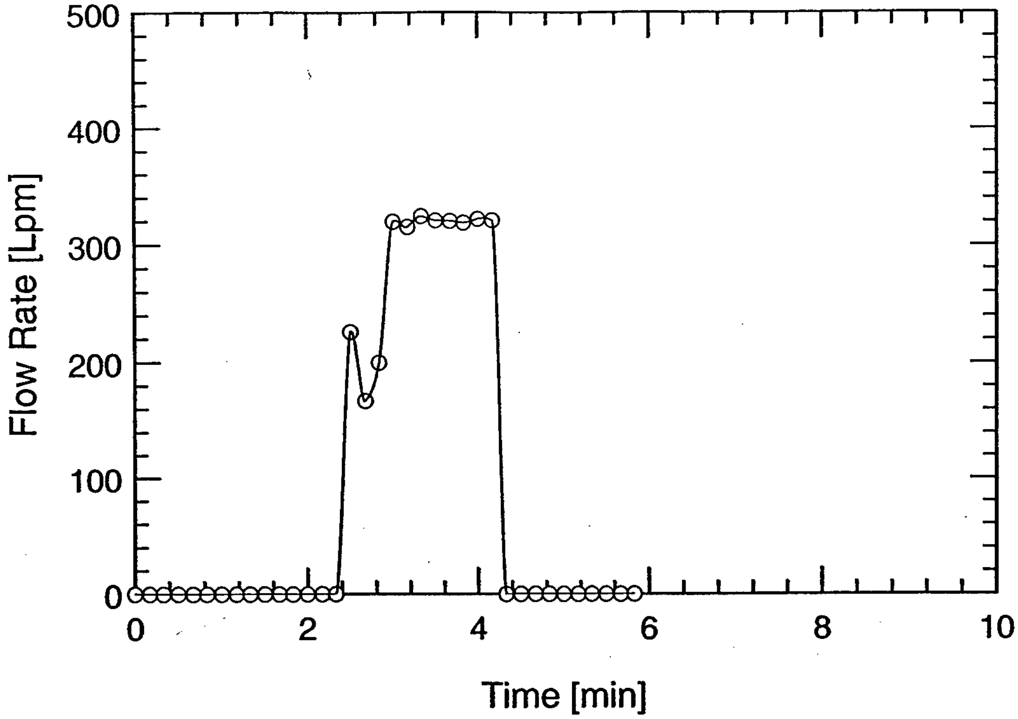
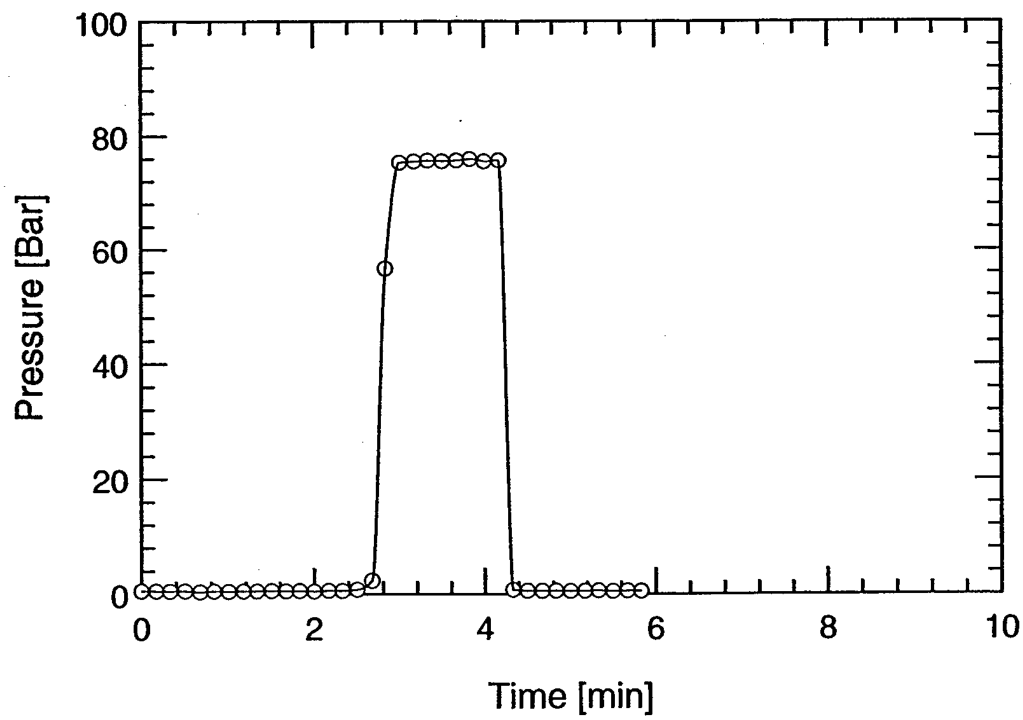


Water Mist System Flow Rate



Water Mist System Pressure

Test #64

Appendix B

System Description

B-1.0 MACHINERY SPACE DESIGN REQUIREMENTS

The Navy's water mist system was developed to protect spaces where the primary fire threats are large Class B Fires. The system is designated by NFPA 750 as a "high pressure single fluid"—"total compartment application system." The system is intended to provide complete protection of an enclosed or partially enclosed space. This protection is achieved by the simultaneous operation of all nozzles in the compartment.

The system shall consist of two levels of nozzles (installed on the under side at each deck level) nominally spaced 2.4-3.0 m (8-10 ft) apart. The system shall be designed to operate at a pressure of 70 bar (1000 psi) and uniformly discharge water mist at a rate of 0.40 Lpm/m^3 (0.003 $gpm/ft^{3)}$. Two-thirds of the water 0.27 Lpm/m^3 (0.002 gpm/ft^3) shall be discharged from the overhead nozzles and one-third 0.13 Lpm/m^3 (0.001 gpm/ft^3) from the intermediate level nozzles. The system shall be designed to meet these flow characteristics (flow rate per unit volume) within ± 5 percent.

B-2.0 COMPARTMENT DETAILS

The system design was developed and tested in a closed compartment with the ventilation system secured. These are the desired compartment conditions during system activation. However, if the compartment is not secured or the ventilation system remains active, full scale test data provides a high degree of confidence the system will still extinguish the fire.

B-3.0 WATER MIST NOZZLES

B-3.1 Nozzle Description

The Navy's water mist nozzle consists of a Spraying Systems Model 7N nozzle (or equivalent) with some minor modifications (Fig. B1). The 7N nozzle consists of a

multi–orifice body housing seven removable orifice cap assemblies. An orifice assembly consists of a cap housing with a press-filled orifice and an orifice insert designed to swirl the water. Six of the orifice cap assemblies are arranged in a circular pattern around the body of the nozzle 60° apart. These six orifice cap assemblies are installed on flat surfaces cut into the nozzle body. The flat surfaces provide these six orifice caps with a spray of 60° measured off of the vertical centerline of the nozzle. The seventh orifice cap assembly is installed pointing vertically down the centerline of the nozzle. When purchasing a model 7N nozzle from Spraying Systems, all seven orifice cap assemblies are the same size and capacity. The Navy's nozzle shall consist of various size and capacity orifice cap assemblies as described in the following paragraph.

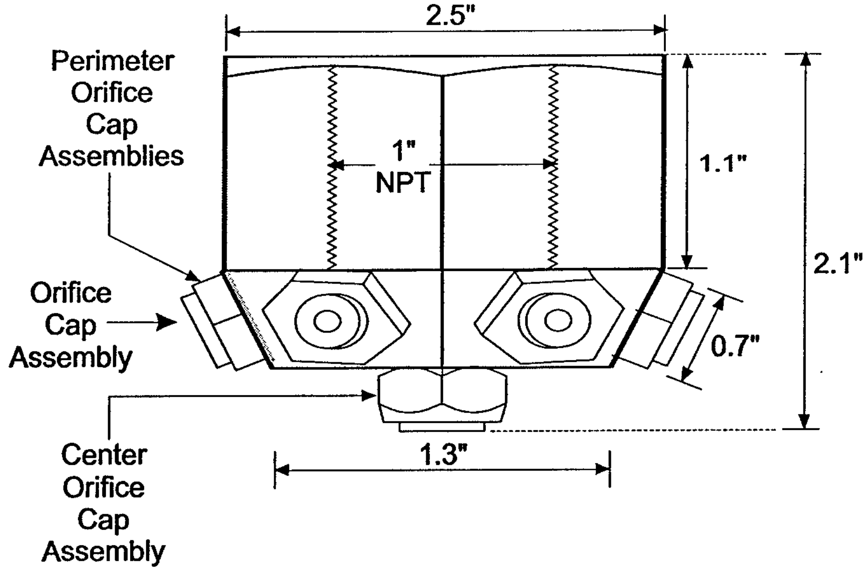
For typical Navy machinery space installations, two orifice arrangements (7N nozzle configurations) will be included in the design. The nozzles installed in the overhead of the machinery space shall consist of six 1/4LN2 orifice caps (CP1206 and CP1207-2-SS) with 1/4LN26 orifice inserts (3781-26) installed around the perimeter of the nozzle and a 1/4LN12 orifice cap assembly (including a 1/4LN12 orifice insert) installed in the center. The nozzles installed at the intermediate level shall consist of six 1/4LN1.5 orifice caps (CP1206 and CP1207-1.5-SS) with 1/4LN26 orifice inserts (3781-26) and a 1/4LN2 orifice cap assembly (including a 1/4LN2 orifice insert) installed in the center.

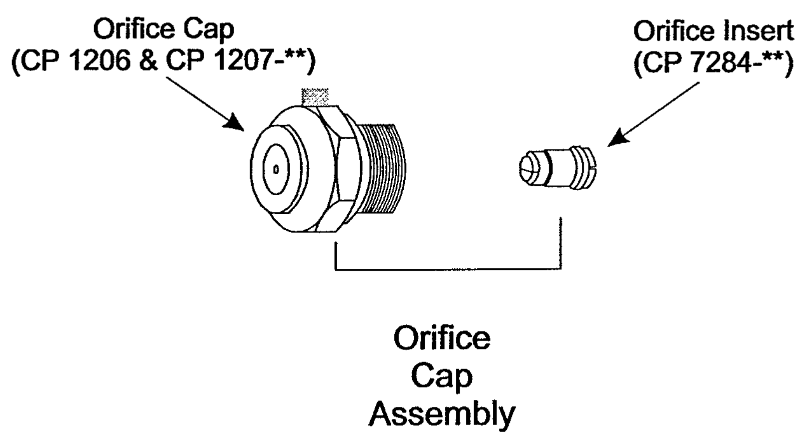
The inlet to the nozzle is a 1 in. Female NPT connection. The final modification consists of installing a strainer in each nozzle. The strainer shall consist of 100 mesh screen and shall be installed in the throat of each nozzle. The threaded adapter connecting the nozzle to the pipe network shall be custom manufactured for this application and have a maximum clear passage area of 0.32 cm^2 (0.05 $in.^2$).

B-3.2 k-Factor

The upper level nozzles have a k-factor of 1.43 Lpm/$bar^{1/2}$ (0.10 gpm/$psi^{1/2}$) producing a flow rate of 13.25 Lpm (3.5 gpm) at a 70 bar (1000 psi) nozzle pressure. The intermediate level nozzles have a k-factor of 0.72 Lpm/ $bar^{1/2}$ (0.05 gpm/$psi^{1/2}$), producing a flow rate of

Spraying Systems Model 7N Nozzle Body (1-7N)





*Note: ** are size designations*

Fig. B1 – Water mist nozzle

5.7 Lpm (1.5 gpm) at a 70 bar (1000 psi) nozzle pressure. The system shall be designed to produce an operating pressure (nozzle pressure) of 70 bar (1000 psi) ± 10 percent.

Hydraulic calculations for the system shall be conducted using the friction loss equations developed by Darcy-Weisbach as recommended by NFPA 750.

B-3.2 Drop Size Distribution

The average drop size distribution of the two Navy nozzles measured at a distance of 1.0 m (3.3 ft) below the nozzle falls in the category of a "Class 2 Spray" as defined by Appendix 1.3 of NFPA 750 (D_V 0.9 $\leq$ 400 microns). The actual drop sizes are D_V 0.1 $\approx$ 50 microns, D_V 0.5 $\approx$ 175 microns and a D_V 0.9 $\approx$ 300 microns.

B-4.0 NOZZLE LOCATIONS

B-4.1 Nozzle Elevation

Water mist system designs for spaces with overhead heights greater than one deck level shall consist of nozzles installed at two elevations: high in the overhead of the space and an intermediate level. Typically, these elevations correspond to deck levels. The system shall be designed to provide 67 percent of the total system flow rate high in the space (through overhead nozzles) and 33 percent of the total system flow rate at the intermediate elevation.

B-4.2 Nozzle Spacing

The nozzles shall be uniformly spaced in a grid with nozzle locations a maximum of 3.0 m (10 ft) apart. Nozzle spacing may decrease to achieve a uniform grid spacing. The nozzle locations shall be staggered between elevations for the upper level of nozzles, the distance from the first row of nozzles to an adjacent bulkhead shall be no greater than one-half the maximum grid spacing. To achieve a staggered nozzle spacing between nozzle grids

(elevations), the first row of the intermediate level of nozzles shall be installed approximately one nozzle grid spacing away from the adjacent bulkhead. Consequently, the lower nozzle grid may contain less nozzles than the upper nozzle grid.

Upon completion of the nozzle grid layout, each individual nozzle location needs to be evaluated. The initial evaluation consists of positioning each nozzle in the center of the open area protected by the nozzle. For example, if one-third of the right side of the square is occupied by equipment or ductwork, the nozzle should be moved to the left and centrally located between the obstruction and the adjacent nozzles. The minimum and maximum distances between a nozzle and an obstruction are 0.6 m (2 ft) and 1.6 m (5 ft) respectively. The minimum and maximum distances between two nozzles are 1.2 m (4 ft) and 3 m (10 ft), respectively. The volume protected by each nozzle is defined as a square area with a side dimension equal to the nozzle grid spacing and a height equal to the deck spacing (i.e., nominally 2.4 m (8 ft)). If more than 70 percent of the volume is occupied by equipment, the nozzle may be removed. If a horizontal obstruction greater than 0.9 m^2 (10 ft^2) exists between a majority of the volume being protected and the nozzle, the nozzle should be relocated below the obstruction. For ceiling obstructions (i.e., ductwork and stiffeners), the nozzle shall be either located below the obstruction or shall be installed at a distance of at least 1.5 times the depth (vertical distance down) of the obstruction away from the obstruction. Any horizontal obstruction greater than 3.3 m^2 (36 ft^2) must have a nozzle located under the obstruction.